Final Report On

DEVELOPMENT OF A FAST RESPONSE TEMPERATURE GAGE FOR ROCKET VEHICLE PLUMBING SYSTEMS

24 June 1964 - 24 June 1965

NASA Contract NAS8-11699
REC Report 66518A

18 June 1965

Prepared for: George C. Marshall Space Flight Center, Huntsville, Alabama
Author: Truman M. Stickney

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

BIBLIOGRAPHY

1. American Welding Society, Edward A. Fenton, Technical Secretary, "Brazing Manual," Rinehold Publishing Corporation, (1963).

2. Creedon, John E., "Permeation of Hydrogen Through Metals in Thermionic-Converter Applications," USAELRDL Technical Report 2431, United States Army, (1964).

3. Rudd, David N., and Vetrano, J.B., "Permeability of Metals and Enameled Metals to Hydrogen," NAA-SR-6109 Atomic International Division of North American Aviation, Incorporated, (1961).

4. Douglass, R.N., Holden, F.C., and Jaffee, R.I., "High Temperature Properties and Alloying Behavior of the Refractory Platinum-Group Metals," Battelle Memorial Institute Progress Report, (1959).

5. American Iron and Steel Institute, "High Temperature High Strength Alloys," Technical Committee on High Temperature High Strength Alloys, (1963).

6. Wise, E.M., Eash, J.T., "Properties of the Platinum Metals, II: Tensil Strength of Platinum, Palladium and Several of their Commercial Alloys at Elevated Temperatures...," Institute of Metals Division, American Institute of Mining and Metallurgical Engineers Transactions, Volume 128, (1938).

7. Walker, B.E., Erving, C.T., and Miller, R.R., "Thermoelectric Instability of Some Noble Metal Thermocouples at High Temperatures," NRL Report 5792, (1962).

8. Lochman, J.C., "New Developments in Tungsten/Tungsten - Rhenium Thermocouple," ISA Transactions, Volume I, Number 4, (1962).

9. DeLeo, R.N., Werner, V.D., and Hagen, F.W., "Measurement of Mean Temperature in a Duct," Instruments andControl Systems, September 1961.

10. Gowen, F.E. and Perkins, E.W., "Drag of Circular Cylinders for a Wide Range of Reynolds Numbers and Mach Numbers," NACA TN - 2960, (1953).

11. Narshawsky, I. and Scadron, M. D., "Experimental Determination of Time Constants and Nusselt Numbers for Bare-Wire Thermocouples in High-Velocity Air Streams and Analytic Approximation of Conduction and Radiation Errors," NACA TN - 2599, (1952).

12. Glaue, G.E., Simmons, F.S., and Stickney, T.M., "Radiation and Recovery Corrections and Time Constants of Several Chromel-Alumel Thermocouple Probes in High-Temperature, High-Velocity Gas Streams," NACA TN - 3766, (1956).

13. Stickney, T.M., "Recovery and Time-Response Characteristics of Six Thermocouple Probes in Subsonic and Supersonic Flow," NACA TN - 3455, (1955).

14. Moffat, Robert J., "Gas Temperature Measurement," Temperature Its Measurement and Control in Sciencs and Industry, Volume III, Part 2, pp. 553-571, (1962).

Final Report On

DEVELOPMENT OF A FAST RESPONSE TEMPERATURE GAGE FOR ROCKET VEHICLE PLUMBING SYSTEMS

24 June 1964 - 24 June 1965

SUMMARY. A fast response temperature gage was developed for use in rocket vehicle plumbing systems involving gas temperatures to 1500° C and gas pressures to 800 PSIG. A high temperature, high pressure gas flow facility was also developed and fabricated for proof testing three breadboard units. All of the specified tests were passed successfully, and nine prototype units were delivered to NASA Marshall Space Flight Center according to the terms of Contract NAS8-11699.

INTRODUCTION. Improvement in the efficiency and reliability of rocket propulsion systems often requires an accurate measurement of total temperature at one or more points in the vehicle plumbing system. An example of such a requirement is the gas generator system of the Saturn vehicle F-1 and J-2 engines. Use of convential jet-engine tailpipe type temperature gages in this application is out of the question for a number of reasons, namely:

1. The tips of the gage would melt
2. The gage stem would crack under the aerodynamic load
3. The gage would leak hydrogen gas
4. The accuracy and time response would be unacceptable even if the gage survived

An appreciation of the problems can be realized by noting the range of flow parameters and gas properties for which the temperature gage is designed.

This report will first cover the requirements and then the results of a materials survey and engineering analysis, followed by the development of the gage design and test facilities, and finally the results of the proof tests.

REQUIREMENTS. The design guidelines for development of the temperature gage are listed below.

2.1. Gas Temperature. 0 to 800° C continuous, and 1500° C for 10 seconds.
2.2. Gas Density. .02 to 4.0 pounds/feet^3.
2.3. Gas Velocity. 0 to 7000 feet/second.
2.4. Gas Pressure. 0 to 800 PSIG.
2.5. Mounting. 7/16 - 20 threaded insertion.
2.6. Mounting Boss Depth. 0.5 inch.
2.7. Maximum Immersed Length. 2 inches.
2.8. Mounting Structure Temperature. -20 to 400° C.
2.9. Mounting Structure Temperature Rate of Increase. 200° C per minute, maximum
2.10. Time Response. 100 milliseconds time constant for the indication of 63 percent of a temperature step change for room temperature to 200° C at 16 pounds per second gas weight flow in an 8 inch diameter pipe.
2.11. Maximum allowable error due to mounting conditions and probe configuration. ±1.0 percent of indicated output.

2.12. Vibration Requirements. 20 - 2000 cps at $1.0G^2$/cps random excitation superimposed on 1500 - 2000 cps sinusoidal sweeps at 35 G's peak.

2.13. Output Characteristics. EMF versus temperature desired in preference to electrical resistance versus temperature (open to negotiation).

2.14. Repeatability. ±1.0 percent for a minimum of 100 cycles between the environmental limits.

2.15. Leakage Test. The gage shall be pressure tested at 800 PSIG and 800° C for thirty minutes with helium, during which the leakage through the gage shall be less than one cubic centimeter per minute.

ENGINEERING ANALYSIS AND MATERIALS SUPPLY.

3.1. Establishment of Atmosphere. Before a choice of materials can be made for a device of this type, the nature of the gas atmosphere must be clearly established. The refractory metals such as molybdenum are sensitive to oxidizing conditions and the platinum alloys are sensitive to reducing conditions. It is also most important to know which metalic oxides are likely to be reduced, as will become clear in a later section. Figure 1, reproduced in part from Reference 1, shows the metal to metal oxide equilibrium lines for various oxides as a function of temperature and moisture content. Gas atmosphere "A" is reducing to copper, nickel, iron, and zinc oxides but oxidizing to silica, alumina, and beryllia. Gas atmosphere "B," on the other hand, is reducing only to copper oxide. The American Welding Society Type-2 Standard Atmosphere for natural gas and air furnace brazing has a much lower water vapor content than most rocket exhausts. It is therefore apparent that few oxides will be reduced in the F-1 and J-2 engine applications despite the high percentage of free hydrogen. Since platinum is affected very little from the chemical standpoint as long as silica and iron oxide are in an oxidizing atmosphere, the products of combustion of the F-1 and J-2 engines may be considered as oxidizing to platinum by virtue of the high steam content.

3.2. Permeability to Hydrogen. Choice of gage materials should also be made on the basis of the permeability of various metals and non-metals to hydrogen gas at high pressure and temperature. Figure 2 from Reference 2 shows a sizeable difference between the permeation rate of nickel and molybdenum. Reference 3 shows that various metal oxide coatings can reduce the permeation rate markedly, but the tests were run under laboratory conditions at a maximum pressure of two atmospheres. Reference 4 suggests that the permeation rate of hydrogen through platinum is of very low order.

3.3. High Temperature Strength. There are a number of so-called super alloys which exhibit extraordinary strength at moderately high temperatures, (Figure 3 and Reference 5), but very few are recommended for use above 1000° C. AISI Type 680 alloy is interesting in that its relatively low strength at the lower temperatures is compensated by adequate strength and good anti-corrosion properties to 1200° C. The platinum alloys (Reference 4 and 6) exhibit much lower room temperature strength, but show to advantage above 1200° C.

3.4. Other Material Properties. If a choice exists, materials in the sensing zone of the gage should exhibit high thermal conductivity and low specific heat to improve accuracy and time response in that order. A low thermal conductivity material should comprise the mounting stem to reduce the heat conduction losses to the wall. The specific heat of the sensing element should not increase radically with temperature if fast response at very high temperatures is a requirement. The specific heat variation for several Noble metals is shown in Figure 4 Reference 4.

3.5. Choice of Thermoelement. For the temperature range of this application, the choice of thermoelement is simply a choice between sensitivity and stability. The long-term drift of platinum-rhodium thermocouples at very high temperatures has been attributed to volatilization of rhodium and subsequent deposition on the platinum leg with consequent reduction in thermoelectric power. Such effects are markedly reduced by utilizing alloy wires in both legs, but at the expense of much reduced sensitivity. Rosemount Engineering Company proposed and indeed purchased the Degussa 70 - PT 30 - RH versus 94 PT 6 RH wires for this contract, but the combination could not be worked into the vehicle circuitry. Of greater import as far as stability is concerned are reactions with various metal oxides. Under reducing conditions, silicaneous attack of platinum can be quite severe, and iron alloying can result from iron oxide reduction. The United States Naval Research Laboratory has conducted tests where the thermoelectric stability of platinum in contact with a number of oxides is evaluated. At 1400° C the EMF charge of the wire exposed to ferric oxide was 100 to 200 times greater than the charges for other oxides, (Reference 7). This emphasizes the importance of the iron oxide equilibrium lines in Figure 1. Use of tungsten-tungsten rhenium was considered due to recent improvements in its stability (Reference 8), but the stability under cyclic conditions is not within the ± 1 percent requirement and tungsten brittleness remains as a problem in fabrication. At the present state of the art 90-PT 10RH versus PT shows to great advantage for the short duration cyclic type applications.

3.6. Velocity and Temperature Distribution. Since the temperature gage is to be mounted in a pipe, the mechanical stresses in the gage mounting stem will be greatly affected by the distribution of velocity and temperature of the gas within the pipe. Figure 5 from Reference 9 shows the distribution for fully developed laminar and fully developed turbulent flow. A distribution close to that shown by Curve 1 was used for the stress analysis of the gage stem.

3.7. Aerodynamic Loading. The drag coefficient of a short cylinder in crossflow is independent of Mach number in low velocity gas flows, but shows large Mach number effects in transonic flow, (Figure 6 and Reference 10). At 815 PSIA total pressure, the loading of a 1/4 inch diameter cylinder can exceed 140 pounds per inch in a uniform flow field.

3.8. Choice of Mounting Stem Design. In consideration of the above, the general design approach was soon arrived at and many former candidate materials went the way of many candidates. Table I summarizes the thoughts on design approach. A single piece mounting stem of AISA Alloy 680 was chosen, and the design is shown in Figure 7. From dynamics considerations, it was desired that the center of mass be in the vicinity of the mounting threads. Figure 8 shows that the mass distribution is near optimum.

3.9. Computation of Mounting Stem Load Safety Factors. A worst-case stress analysis was performed to indicate the factor of safety based on 0.2 percent offset yield strength for four mounting stem stations with gas flowing at sonic velocity and for total pressure and total temperature of 800 PSIG and 800° C respectively. The first station evaluated was at the lead-end of the mounting threads where the temperature was assumed to be 400° C. Succeeding stations were spaced one-half inch apart. The end of the mounting stem, (Figure 7), was extended to two inches total immersion length at the 1/4 inch diameter to represent the loading due to the sensing head. The velocity, drag coefficient (Figure 6) and temperature for each station were evaluated using Curve 1 of Figure 5. The computed applied stresses, the AISI 0.2 percent yield stresses, and safety factors are listed in Table II. Although such a test was not listed as a contract requirement, a high temperature static load test was actually conducted on the stem shown in Figure 7. The equivalent of a 305 pound concentrated load was applied between stations 3 and 4 with station 4 temperature at 790° C and station 1 temperature above 350° C. Post-test examination showed that the yield point had not been exceeded. Figure 9 shows the test in progress.

3.10. Computation of Estimated Time Constant. To determine if an 8.5 mil diameter thermoelement would be small enough to meet the time response requirement, time constants were computed for both coaxial and solid wire elements at the specified flow conditions. The methods of references 11 and 12 were employed for determination of the response of a long wire in cross flow. A form factor based on data in reference 13 was used to represent the response of a U-shaped element. The computation, which also shows the effect of a one-mil diameter tolerance, is summarized in Table III. As can be seen in the table, the use of a coaxial element yields faster response and allows more shield lagging effect. The effect of the shields was not considered in this particular analysis.

3.12. Computation of Conduction Error. To assist in the evaluation of conduction error test results, an electrical analog of the heat conduction paths involved in the later designs was established. Table IV shows the analog and the computation of conduction error for the final breadboard design for three temperatures at the 225 PSIG pressure condition. Wall temperature in each case is assumed to be half the value of total temperature in degrees centigrade. The following heat transfer relations were used:

3.12.1. Element: $Nu = 0.43 + 0.683\, Re^{.466}\, Pr^{0.3}$

3.12.2. Shield: $Nu = 3.65 + \dfrac{.0668\, Y}{1 + .04Y^{.67}}$

The terms and computational procedures are familiar to the student of heat transfer and will not be elaborated upon here.

DEVELOPMENT OF SENSING HEAD DESIGN. Figure 10 shows the various stages in the development of the platinum -10 percent rhodium sensing head design starting with the design of the original proposal. Some of the problems inherent in temperature gage design are enumerated upon in Reference 14.

4.1. Abandonment of the Bare Wire Thermoelement. It soon became obvious that the originally proposed bare wire thermoelement was impractical for the rocket vehicle plumbing system application. This came about first from a realization of the possibility of having a reducing atmosphere to iron oxide under very fuel-rich conditions. As pointed out previously, this could lead to large shifts in thermocouple output. Next it was realized that a true hermetic seal to hydrogen at 400° C and 800PSIG pressure was not an immediate possibility. At this point the decision was reached to incorporate a previously developed platinum - 10 percent rhodium sheathed coaxial thermoelement. This enabled the use of metal to metal welded gas tight seals and provided shielding of the thermocouple wires from contamination by oxide laden gas atmospheres.

4.2. Pre-Breadboard Design. The design of Figure 10-b was fabricated and tested to determine if the coaxial thermoelement and more rugged shield structure would adversely affect the time response. The test results were so encouraging that it was felt that further strengthening of the shield structure would be allowable.

4.3. First Breadboard Design. As indicated by Figure 18 the time response of the design shown in Figure 10-c proved to be most disappointing. The design changes called out in the figure would normally not be expected to produce a factor of three increase in time constant. It was concluded that the flared inlet had caused boundary layer separation such that the lagging effects of the shields were associated with the gas flow intercepted by the thermoelement.

4.4. Second Breadboard Design. The flared inlet was eliminated in the next design, but this yielded only moderate improvement to the gage time response. Something in addition to boundary layer separation was occuring here. A series of experiments was conducted on serial number 3 gage. First, the inner shield exit port was enlarged to raise the internal Mach number to 0.4; an eight percent improvement in response resulted. Next, the boundary layer control tube was removed; a ten percent slower time response resulted. Finally, deep flats were ground in the mounting stem to cause a radical change to the conduction heat loss circuit; little or no change was noted in this last experiment. It was then postulated that the trouble may be in the flow distribution. In other words, if the gas mixing at the exit ports of the three shields favored the outer shields, the inner core gas flow could be at Mach number 0.1 instead of 0.4. That such an action might occur is intuitively evident by examination of Figure 10-d.

4.5. Third Breadboard Design. Separate inner and intermediate shield exits were provided in this design, (Figure 10-e). Figure 19 shows much improved response at high weight flows for serial number 4 gage, but need for further improvement at low weight flows. The REC Model 103H reference sensor (Figure 24) was also run in this test sequence. Close agreement between the two units is seen to occur at 100 PSIA total pressure. The 103H data also correlated well with previous data taken at simulated altitude conditions. Above 100 PSIA, all data appeared to be system limited.

4.6. Final Design. For the final design, a 70 - PT 30 - RH wire was employed as a supporting brace for a longer coaxial thermoelement. The intermediate shield exit was eliminated and common shield exits were provided. This design is considered to be optimum for the present application and definitely assures control of the inner core gas flow. The intermediate shield flow is now controlled by the annular opening next to the inner core exit tube and the outer shield flow by the tubular flow restriction indicated in Figure 10-f. As will be reported later, these final design improvements yielded the required fast response at the low weight flow condition.

HIGH TEMPERATURE, HIGH PRESSURE FLOW FACILITY. Contract NAS8-11699 included the development and fabrication of a nitrogen gas flow facility to perform high pressure, high temperature tests on the breadboard gages. This phase of the program was performed in the following sequence:

5.1. System Layout. Figure 11 shows a schematic of the flow facility and indiactes the nature of the controls and instrumentation. The HTHP facility, as it has come to be called, was designed for use in testing the effects of high temperature and varying pressure levels on gage accuracy, in determining time response at high weight flows, and in ascertaining the effects of thermal cycling.

5.2. Engineering Analysis. Before a detailed design could be made, mass flow variation and running time had to be computed for a number of prototype designs. The results of the final design computation are given in Figure 12 and 13. A high temperature stress analysis was also conducted according to normal computational procedures. Much effort was also directed at obtaining the proper distribution of flow in and around the gage in order to simulate as closely as possible the flow conditions in the actual application. The test section area is shown in Figure 14 and the final assembly design is shown in Figure 15.

5.3. Fabrication. Assembly of the electrical furnace and the welding of heavy pieces were contracted. The remainder of the fabrication phase was conducted at Rosemount Engineering Company. Figure 16 shows the installation in the basement of the REC aeronautical research laboratory and Figure 17 shows the panel on first floor during one of the conduction error test runs.

PROOF TESTS.

6.1. Development Tests. Early development tests were conducted in the REC 3.5 X 17 inch test section wind tunnel which is visible in the backround of Figure 17. The data of Figure 18, discussed previously, was performed in this facility, as was the data of Figures 20 and 27, and some of the data points shown in Figure 19 and 28. The recovery error data shown in Figure 20 establishes the gage accuracy at low temperatures. The data of reference 13 for the recovery error of a double shielded straight inlet thermocouple in subsonic and supersonic flow suggests that the 117B gage recovery error will not exceed 0.7 percent over the entire specified range of flow-conditions. A previously mentioned high temperature static load test, exploratory gas leakage tests, and mechanical vibration tests also contributed to the development test program.

6.2. Establishment of Detailed Test Procedure. A detailed test procedure for determining the acceptance of the three breadboard units was submitted to NASA MSFC and was approved by the contracting officer. The procedure is appended to this report.

6.3. Testing of Three Breadboard Gages. Three 117B breadboard gages were tested in accordance with REC Procedure 16527 as approved by the NASA MSFC contracting officer 8 March 1965. All tests were passed successfully, and it appears that the gage meets the requirements of the Saturn vehicle plumbing system, as described in Exhibit A of NASA Contract NAS8-11699. A summary of test results appears in Table V.

6.3.1. EVALUATION OF COMBINED RADIATION AND CONDUCTION ERRORS

6.3.1.1. Condition 1: Effect of Temperature at Constant Pressure. Serial number 7 gage was installed in the HTHP flow facility and connected to a Leeds and Northrup Millivolter potentiometer in a series opposing circuit with the 103H reference sensor. A double pole double throw knife switch enabled a reading of total temperature using the 103H sensor and the same potentiometer. Readings were taken at six temperature levels at 70 PSIG total pressure. The data in terms of percent absolute total temperature is plotted in Figure 21 along with the flange temperature characteristic. Depending on transient temperature and/or flow distribution conditions yet to be ascertained, any one of three characteristics could be produced. The effects of flange temperature (Condition 3) is shown in the figure, but there are apparently several contributing factors. Nevertheless the data shows good overall agreement with the results of an electrical analog heat transfer analysis shown by the predicted characteristic.

6.3.1.2. Condition 2: Effect of Pressure at Constant Temperature. Serial number 7 gage was next subjected to pressure variation at approximately 540° C total temperature. The data as plotted in Figure 22 shows good agreement with the computed variation. The same flange characteristic or forcing function used for Condition 1 applied to Condition 2 testing.

6.3.1.3. Condition 3: Effect of Wall Temperature. Figure 23 shows the dependence on what we have termed the forcing function, or the ratio of gas-to-wall temperature difference to the absolute total temperature of the gas. The radiation and conduction corrections are somewhat higher than predicted for low flange temperatures (high F), but are in good agreement otherwise.

6.3.2. EVALUATION OF TEMPERATURE TIME CONSTANTS.

6.3.2.1. Condition 1: High Weight Flow. Serial number 7 gage was subjected to quasi-step changes in temperature from a level of 400° C to 500° C, (depending on weight flow) down to a value corresponding to room temperature. The output transient was recorded on the Model 151-100A Sanborn recorder at four pressure levels. A reproduction of three of the records appears in Figure 26 which shows the emergence of a superimposed second order HTHP system response of the order of 25 milliseconds. The raw data is therefore corrected for this superimposed time response condition. A log-log plot of the corrected data yields a straight line characteristic and thereby substantiates the need for the correction. The response should be a logarithmic function of Reynolds number at the thermoelement and, to a close approximation, the product of free stream Mach number and static pressure. The HTHP facility simulates flow at 0.4 Mach number which is the maximum Mach number at the thermoelement inside the gage. Tests in a heated gas facility having a test section width greater than the gage stem length would give more representative results. Despite some inherent weight flow distribution problems and the 25 millisecond system response, the HTHP facility is both convenient and reliable for obtaining the type of data required in this contract.

6.3.2.2. Condition 2: Low Weight Flows. Serial number 5 gage was mounted in a wind tunnel test section according to Figure 1 of the REC Procedure 16527. Time response was determined at 0.1, 0.2, and 0.21 Mach number (0.3 Mach number was not attainable on date tested). Serial number 7 gage was then tested at 0.2 Mach number, both at zero angle and 40 degrees to the flow (gage turned 40 degrees about its axis). A reproduction of three record charts appears in Figure 27 and the data of this test and the previous test is correlated in Figure 28. The MP product was chosen for correlation purposes in preference to Reynolds number fot the sake of convenience. Reynolds number is actually very nearly proportional to the MP product divided by the square root of absolute temperature. Figure 28 shows that the gage time response requirement has been met.

6.3.2.3. Condition 3: Interchangeability. Serial numbers 5 and 6 were also tested for time response in the HTHP facility at 20 PSIG. At this condition the time constant of the three gages agreed within 5 milliseconds of each other. The corrected values are 75, 85, and 85 milliseconds for serial numbers 5, 6, and 7 respectively.

6.3.3. VIBRATION TEST.

Serial number 6 gage submitted for the vibration test at Environ Laboratories, Incorporated, whose test report is attached. The gage passed the vibration test and appears to be in good condition. Comparison of the initial and the final calibration shows that gage accuracy was not affected by this test.

6.3.4. HIGH PRESSURE, HIGH TEMPERATURE GAS LEAKAGE TEST. All three gages were tested for helium gas leakage at 800 PSIG and 800° C in the facility shown in Figure 2 of REC Procedure 16527. Serial number 5 gage showed no leakage for two minutes and then leaked at a rate greater than 100 cc per minute. The gage was opened up to locate the trouble. It was found that the bulkhead back of the mounting had not been completely welded, but was cold-sealed by filling at one small point. Because of this incident an in-process helium leak test has been incorporated on the process travel card for each gage. The test calls for applications of 850 PSIG helium for a period of five minutes with zero leakage. In attempting to repair serial number 5 gage, one of the leads broke within the ceramic cement potted region. Some rather drastic "surgery" was called for at this point, namely: chemically milling away the Hastelloy-X stem and the ceramic. The operation was successful and the rebuilt gage with the original platinum-rhodium element and head and with new stem and new cement repeated its former calibration, performed normally in the HTHP facility tests, and subsequently passed the high pressure, high temperature gas leakage test with zero leakage. Serial numbers 6 and 7 gages passed the leakage test without difficulty.

6.3.5. THERMOELECTRIC OUTPUT CALIBRATIONS. An initial calibration was performed on all three gages at the start of the test program. The gages were immersed in agitated oil with the level of the bath above the mounting threads. Gage output was read on a Leeds and Northrup Type LK-3 potentiometer. Reference bath temperature was sensed by an REC Model 162F platinum resistance thermometer which was read out on a Leeds and Northrup Model 4735 Wheatstone bridge. Data was obtained at oil bath temperatures of approximately 100° C and 300° C. Table V shows the comparison between initial and final calibration results.

FABRICATION OF PROTOTYPE GAGES. Tooling and processes have been developed at Rosemount Engineering Company to assure that each prototype gage will conform to the operating characteristics delineated in the previous section. While some of the procedures are proprietary, all essential design data has been released to NASA MSFC for use by the government. Figure 29 shows the main piece parts and subassemblies and copies of the final assembly drawing and specification drawing are attached.

CONCLUSIONS. A reliable fast response temperature gage has been developed for use in rocket vehicle plumbing systems. The major design features are:

1. Use of a coaxial thermoelement
2. Use of a platinum - rhodium multishield sensing head
3. Use of a rugged one-piece "super alloy" mounting stem

The success of the program was due more to careful attention to the present state of the art than to important advances thereto.

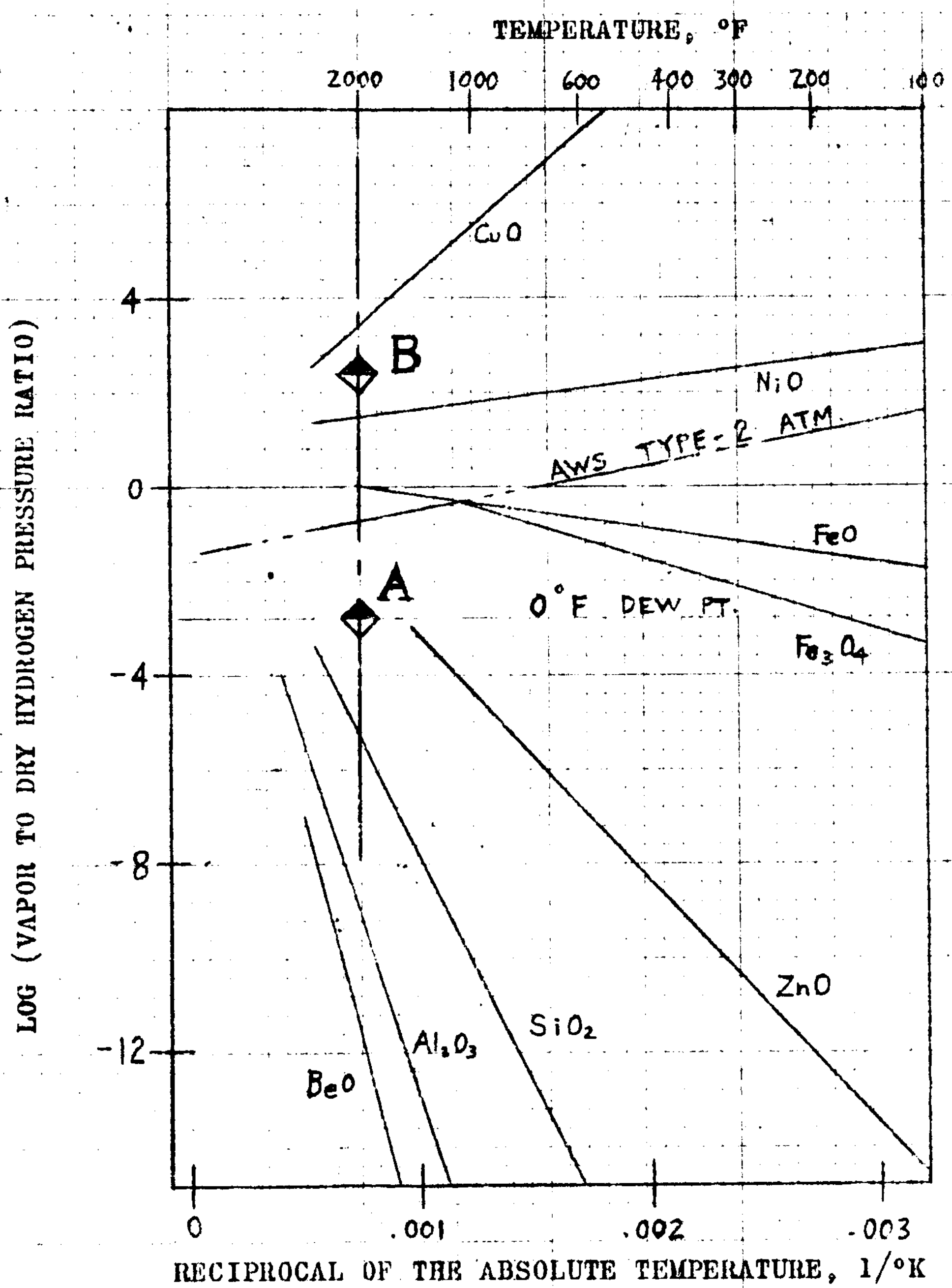


FIGURE 1: METAL–METAL OXIDE EQUILIBRIA IN CONTROLLED ATMOSPHERES

FIGURE 2: PERMEATION RATE OF HYDROGEN THROUGH TWO METALS

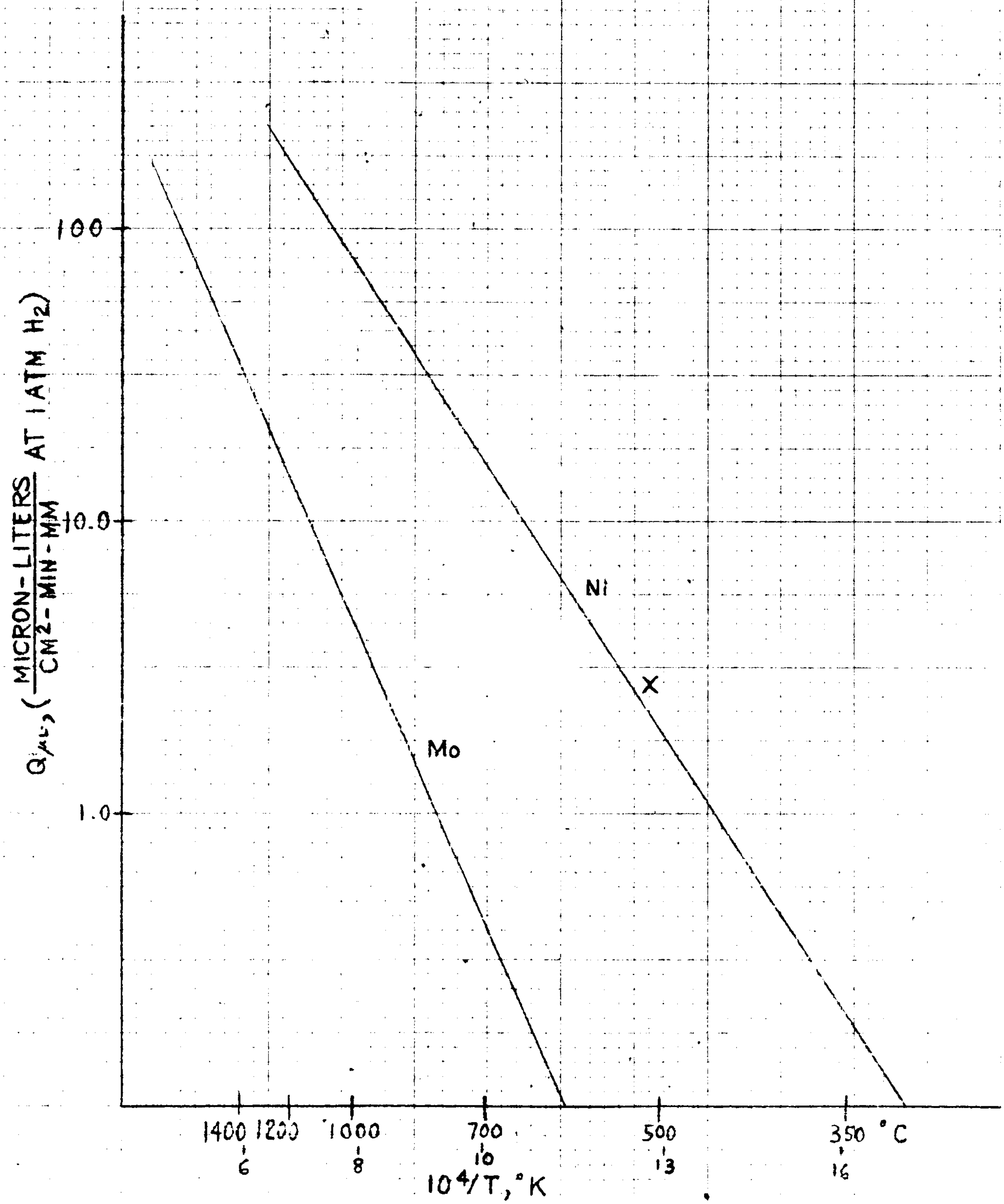
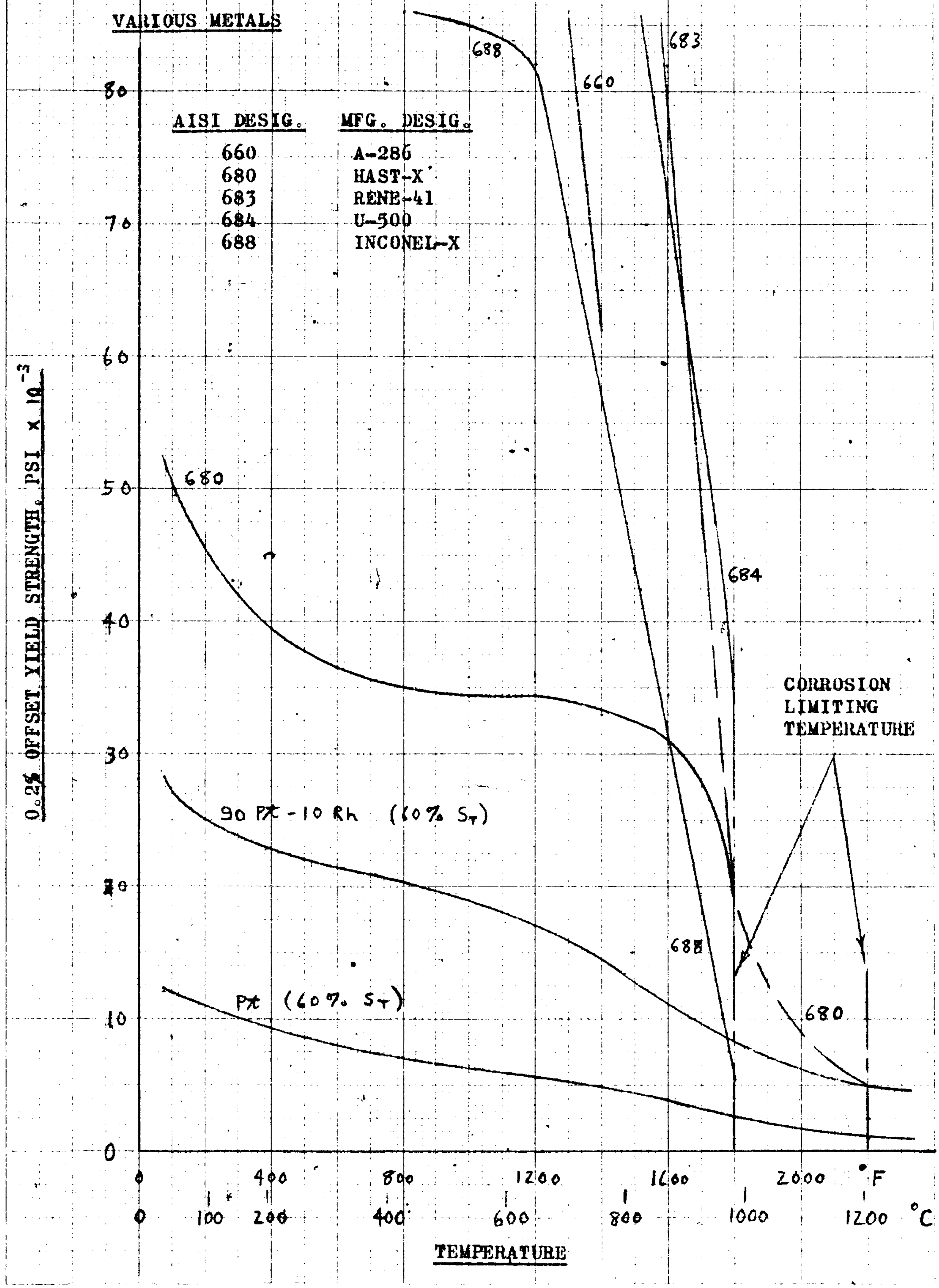


FIGURE 3: HIGH TEMPERATURE 0.2% OFFSET YIELD STRENGTH OF VARIOUS METALS



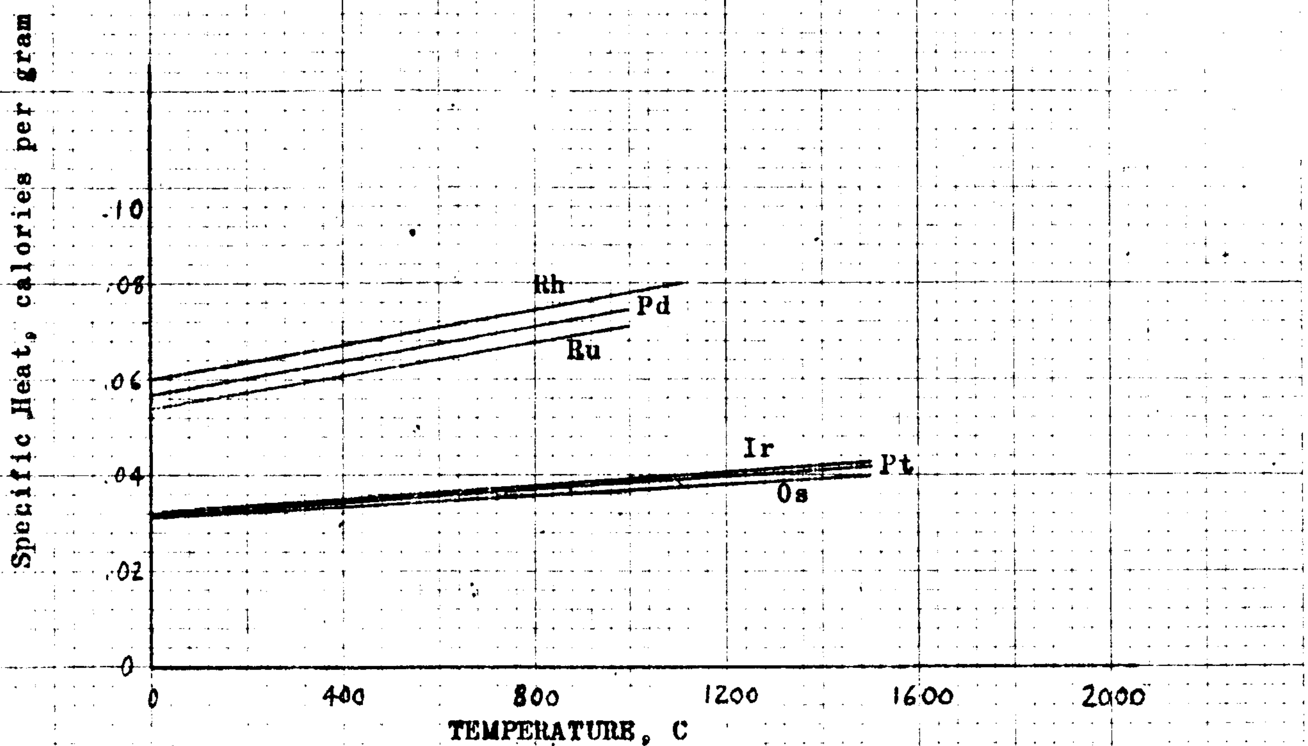


FIGURE 4: EFFECT OF TEMPERATURE ON THE SPECIFIC HEAT OF THE PLATINUM METALS

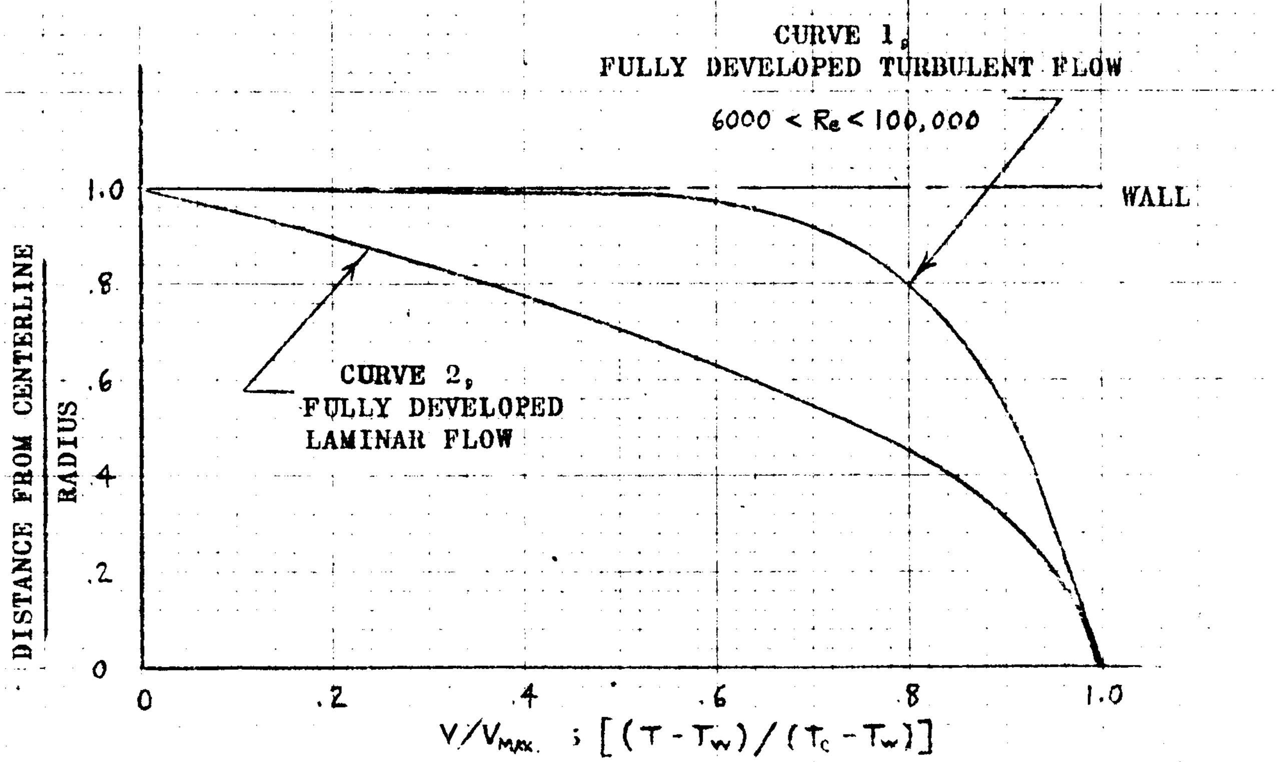
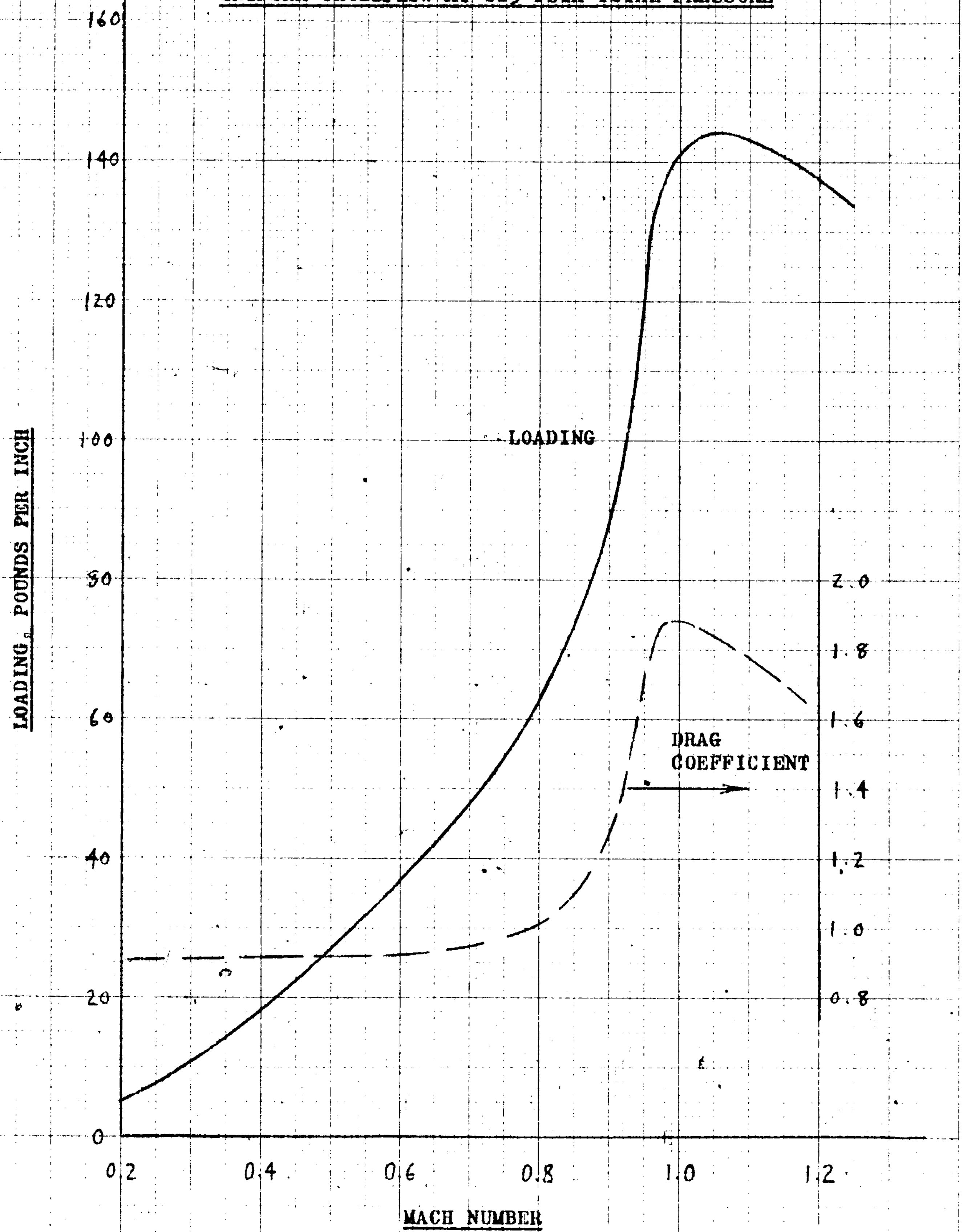
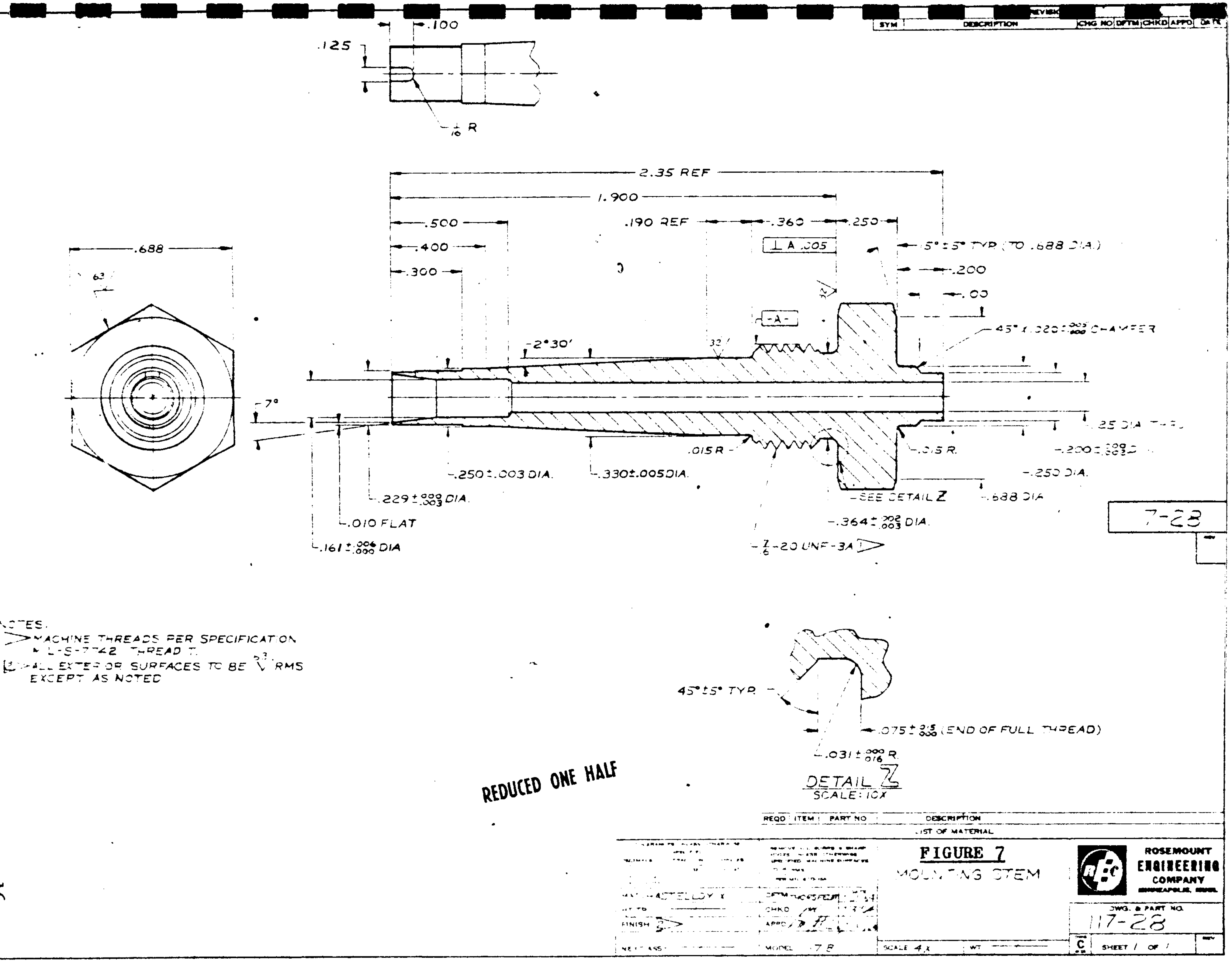


FIGURE 5: VELOCITY AND TEMPERATURE DISTRIBUTIONS IN FULLY DEVELOPED FLOW IN A PIPE. (GASES WITH Pr=1)

FIGURE 6:

AERODYNAMIC LOADING OF A 1/4 INCH DIAMETER CYLINDER IN UNIFORM CROSSFLOW AT 815 PSIA TOTAL PRESSURE





.100
.125
1/16 R
2.35 REF
1.900
.500
.400
.300
.190 REF
.360
.250
⊥ A .005
-A-
5° ± 5° TYP (TO .688 DIA.)
.200
45° X .020 CHAMFER
2°30'
.688
7°
.25 DIA THRU
.015 R
.250±.003 DIA.
.330±.005 DIA.
.229 DIA.
.010 FLAT
.161 DIA
SEE DETAIL Z
.688 DIA
.250 DIA.
.364 DIA.
7/16-20 UNF-3A
7-28
NOTES:
MACHINE THREADS PER SPECIFICATION MIL-S-7742 THREAD
ALL EXTERIOR SURFACES TO BE 63 RMS EXCEPT AS NOTED
45° ± 5° TYP
.075 (END OF FULL THREAD)
DETAIL Z
SCALE: 10X
REDUCED ONE HALF
REQD
ITEM
PART NO
DESCRIPTION
LIST OF MATERIAL
FIGURE 7
MOUNTING STEM
ROSEMOUNT ENGINEERING COMPANY
DWG. & PART NO.
117-28
SCALE 4X
SHEET 1 OF 1

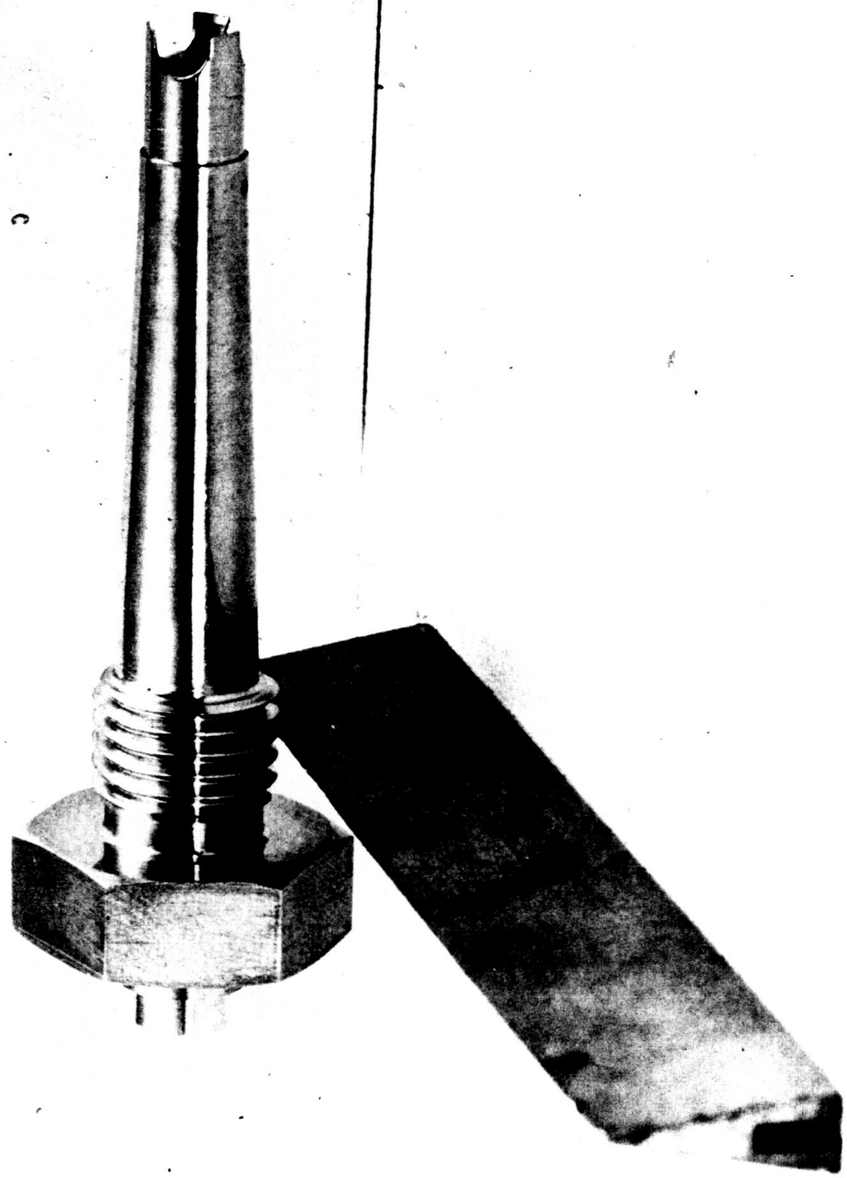


FIGURE 8

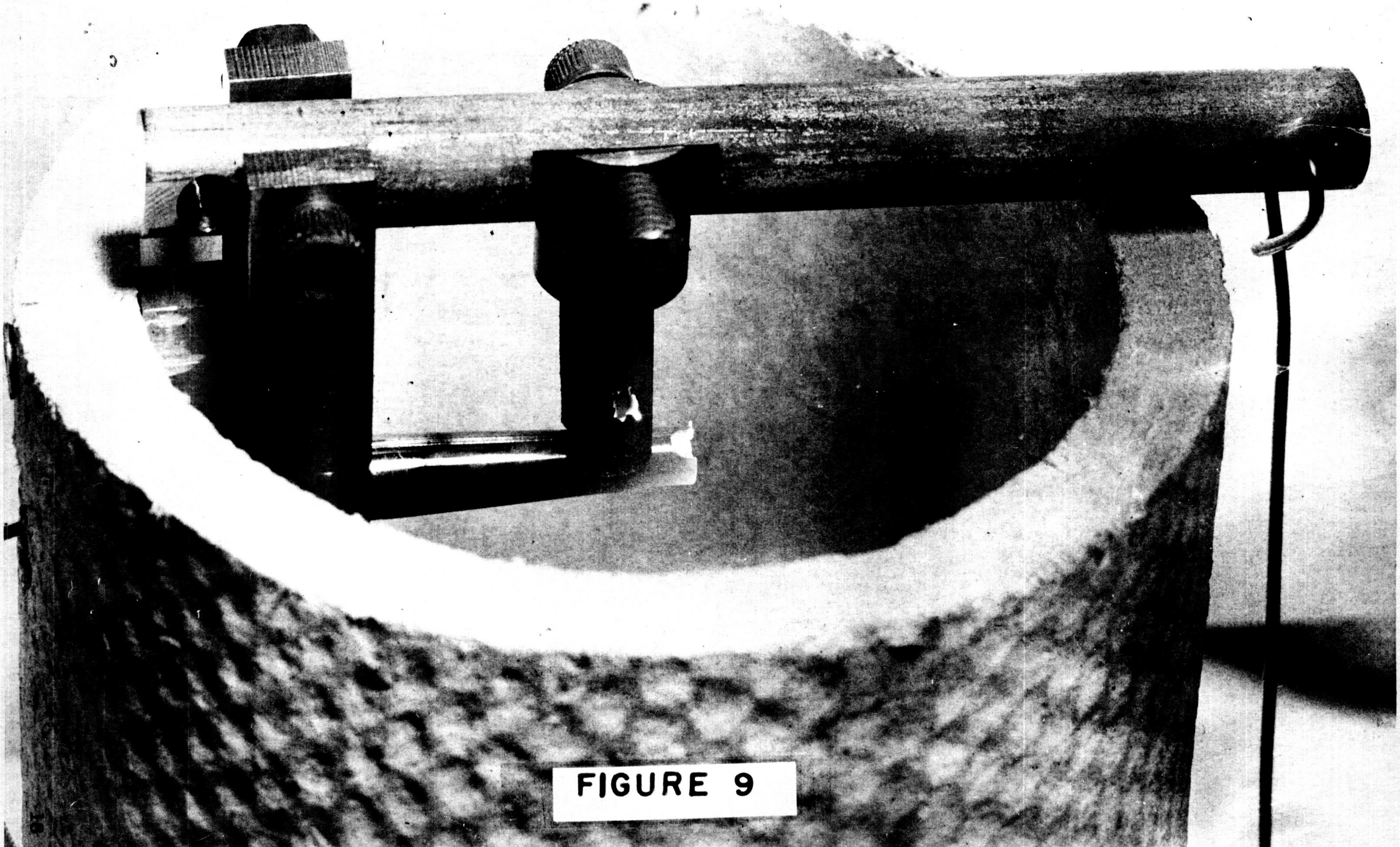
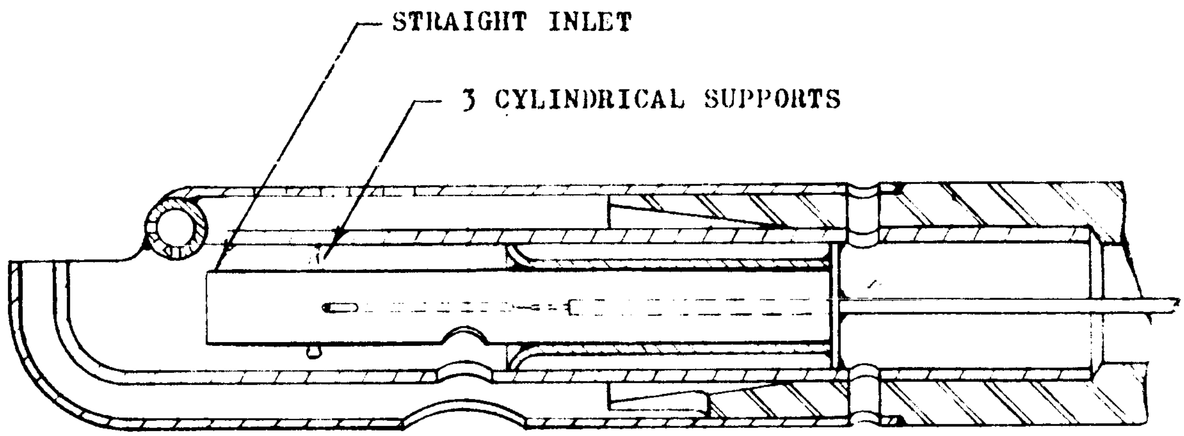
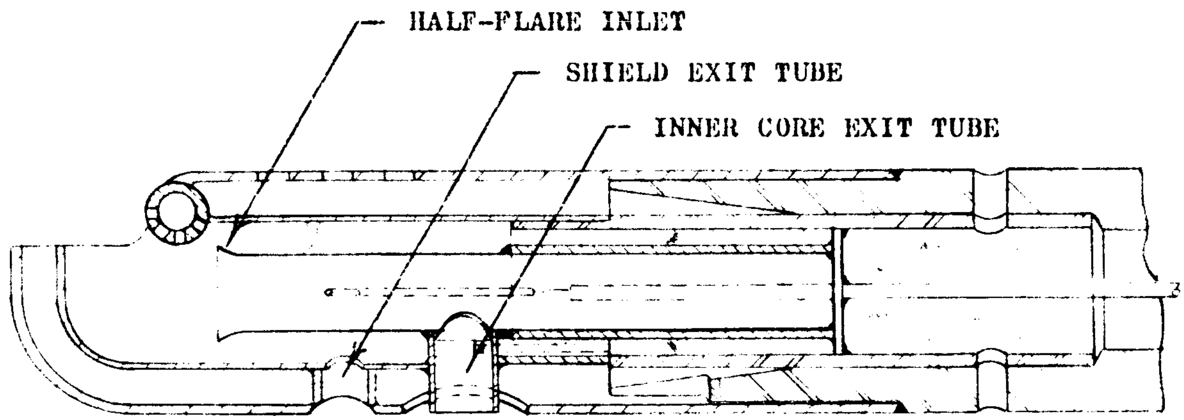


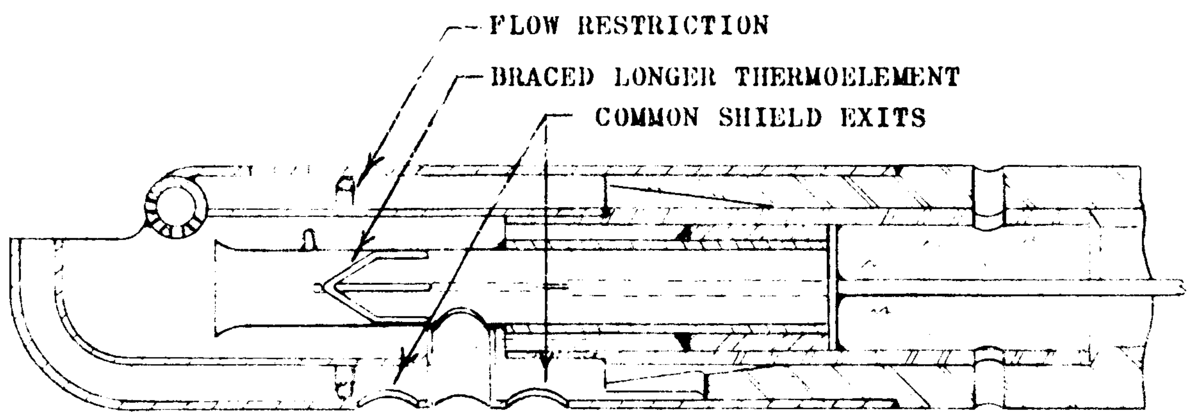
FIGURE 9



d. Second Breadboard Design, Serial No's. 2 & 3

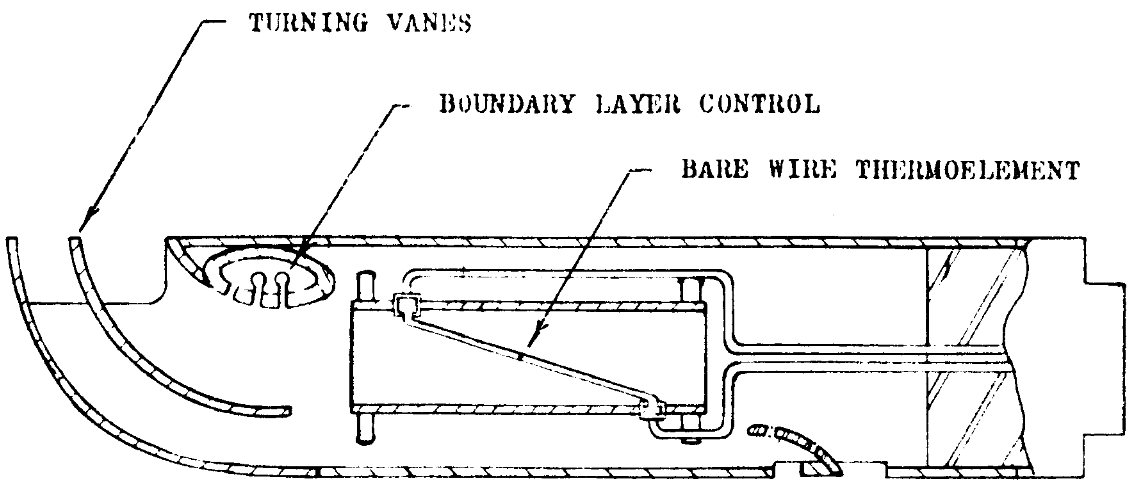


e. Third Breadboard Design, Serial No. 4

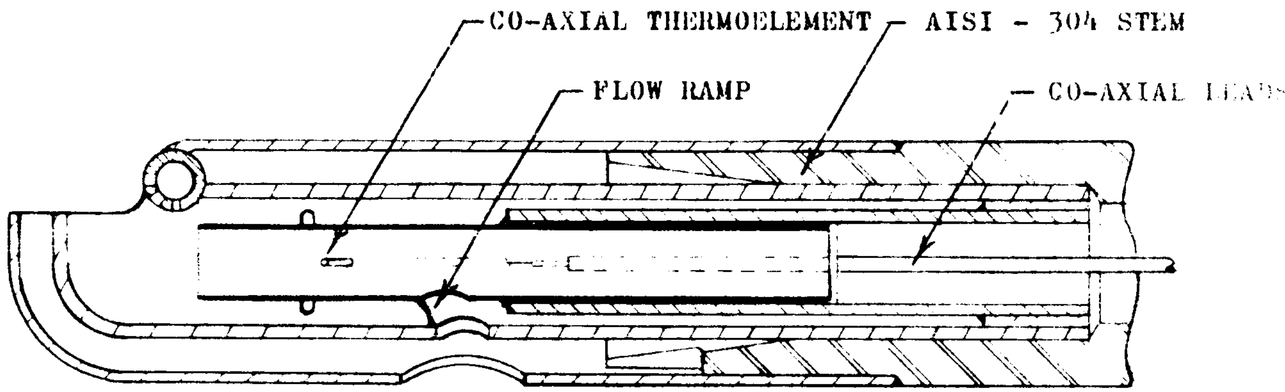


f. Final Design: Breadboard and Prototype Gages

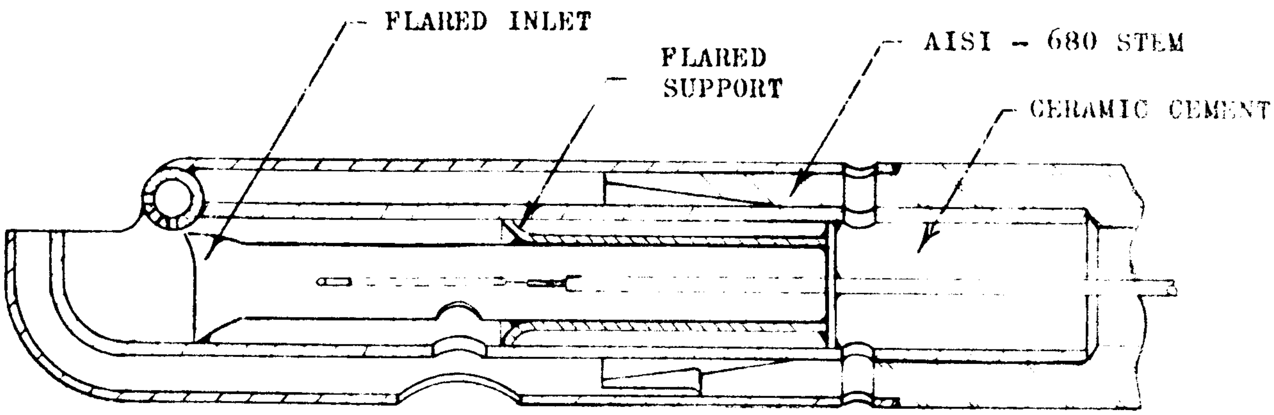
FIGURE 10: DEVELOPMENT OF SENSING HEAD DESIGN (Concluded)



a. Design of Original Proposal



b. Pre-breadboard Design



c. First Breadboard Unit, Serial No. 1

FIGURE 10: DEVELOPMENT OF SENSING HEAD DESIGN

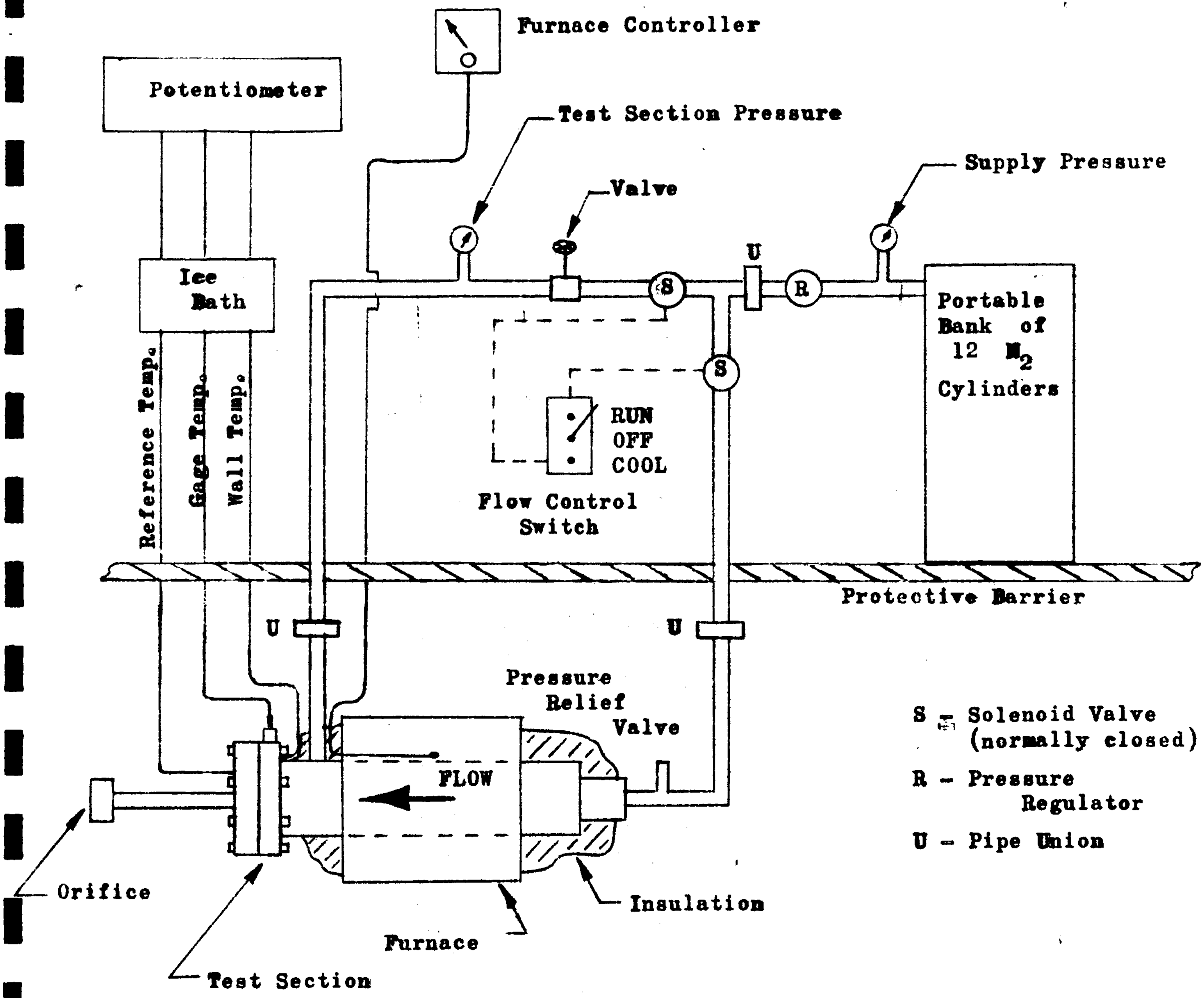


FIGURE 11: Schematic of High Pressure Flow Apparatus

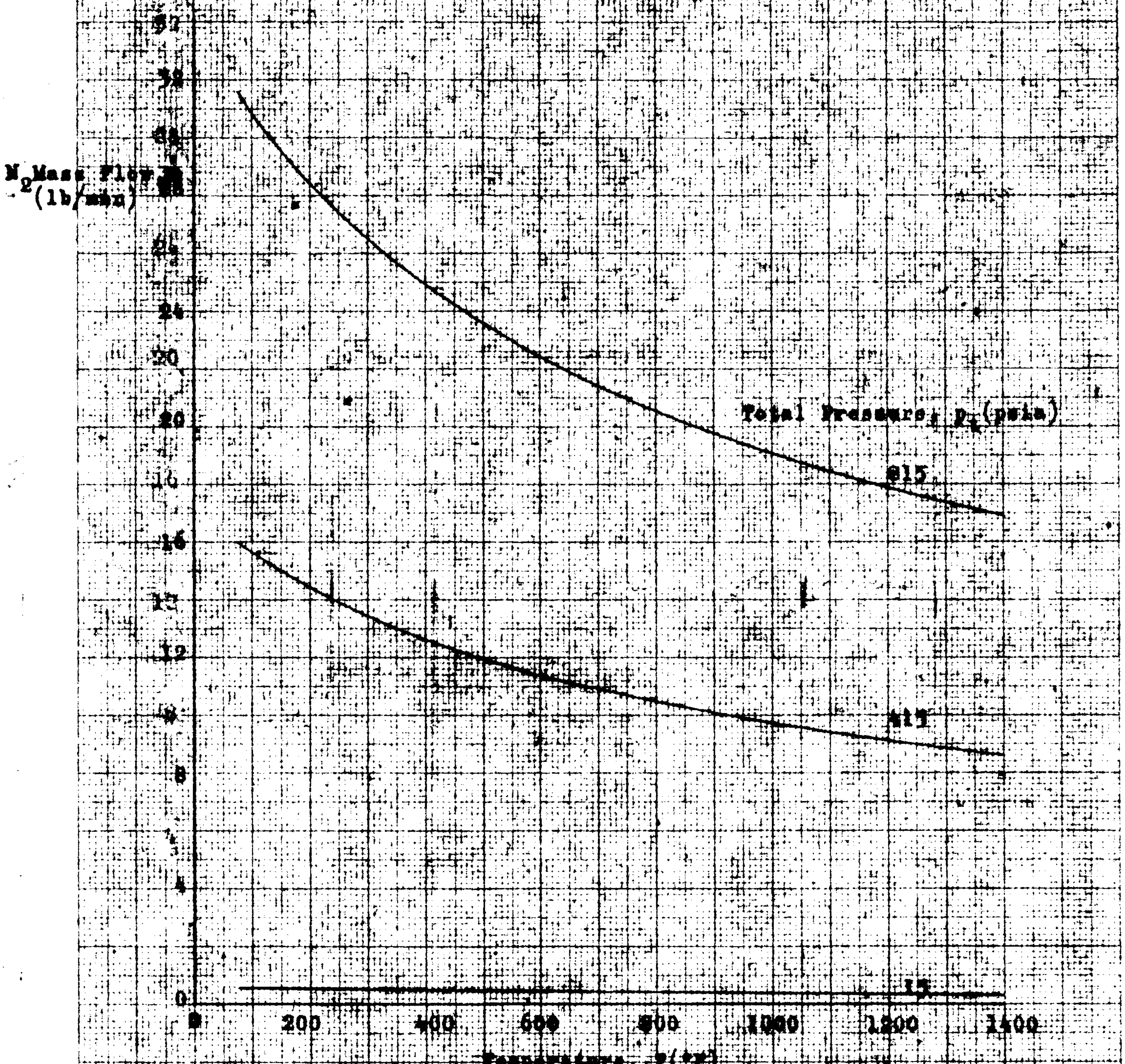


FIGURE 12

N_2 Mass Flow [illegible] for High Pressure Flow Apparatus

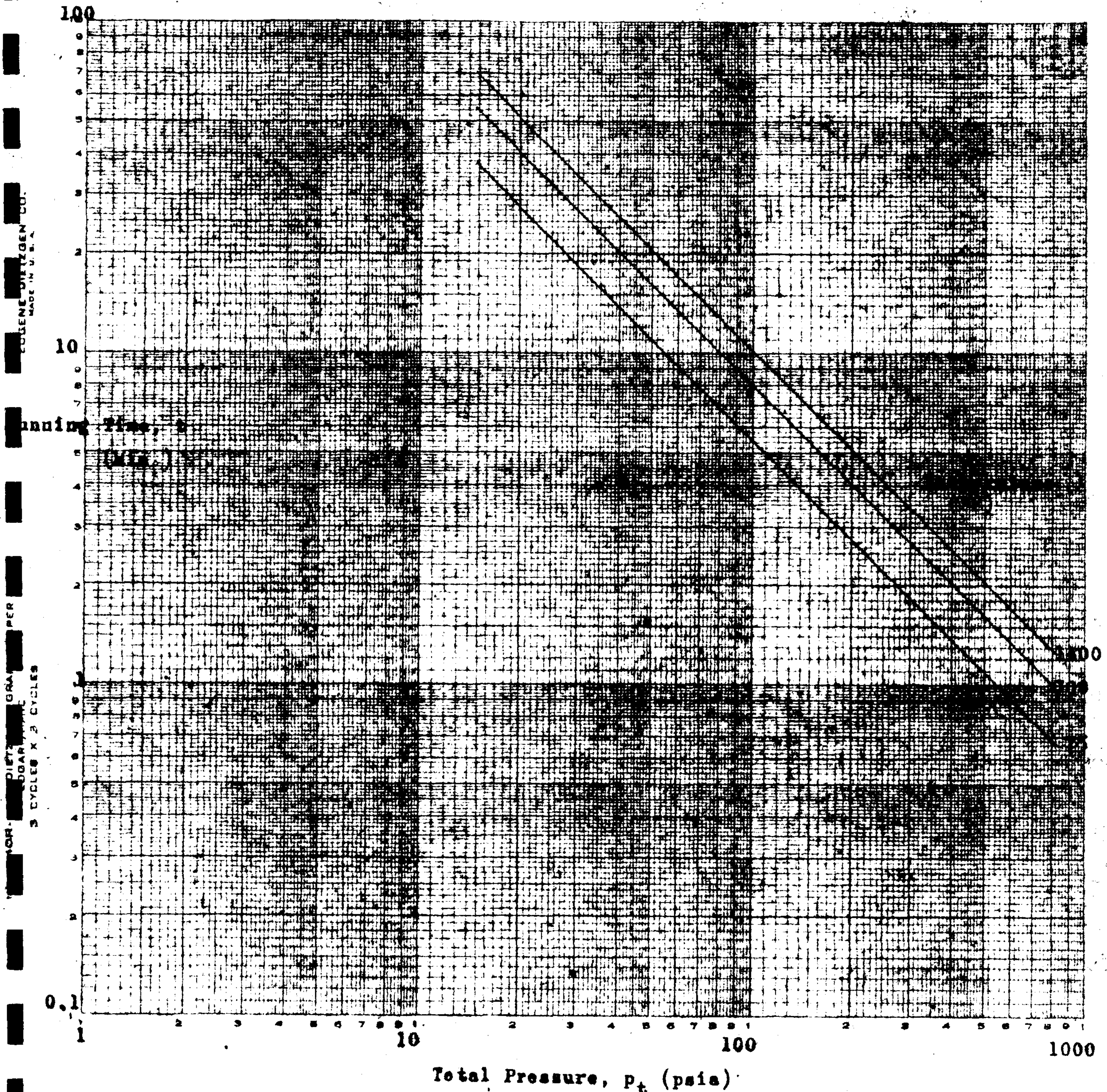
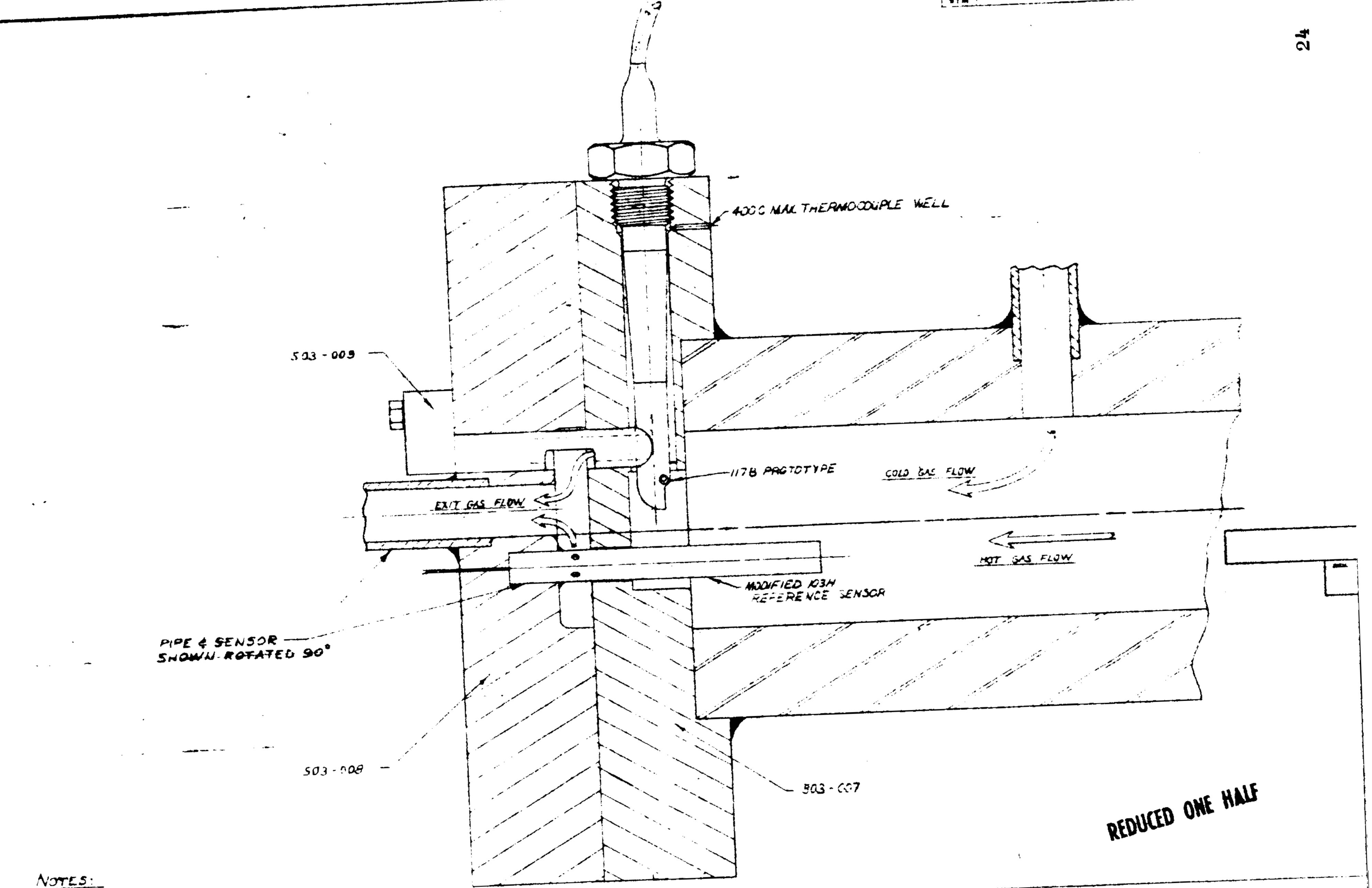


FIGURE 13: Estimated Blow Down Running Time vs. Pressure and Temperature For High Pressure Flow Apparatus



NOTES:

1. FLANGE BOLTS NOT SHOWN.

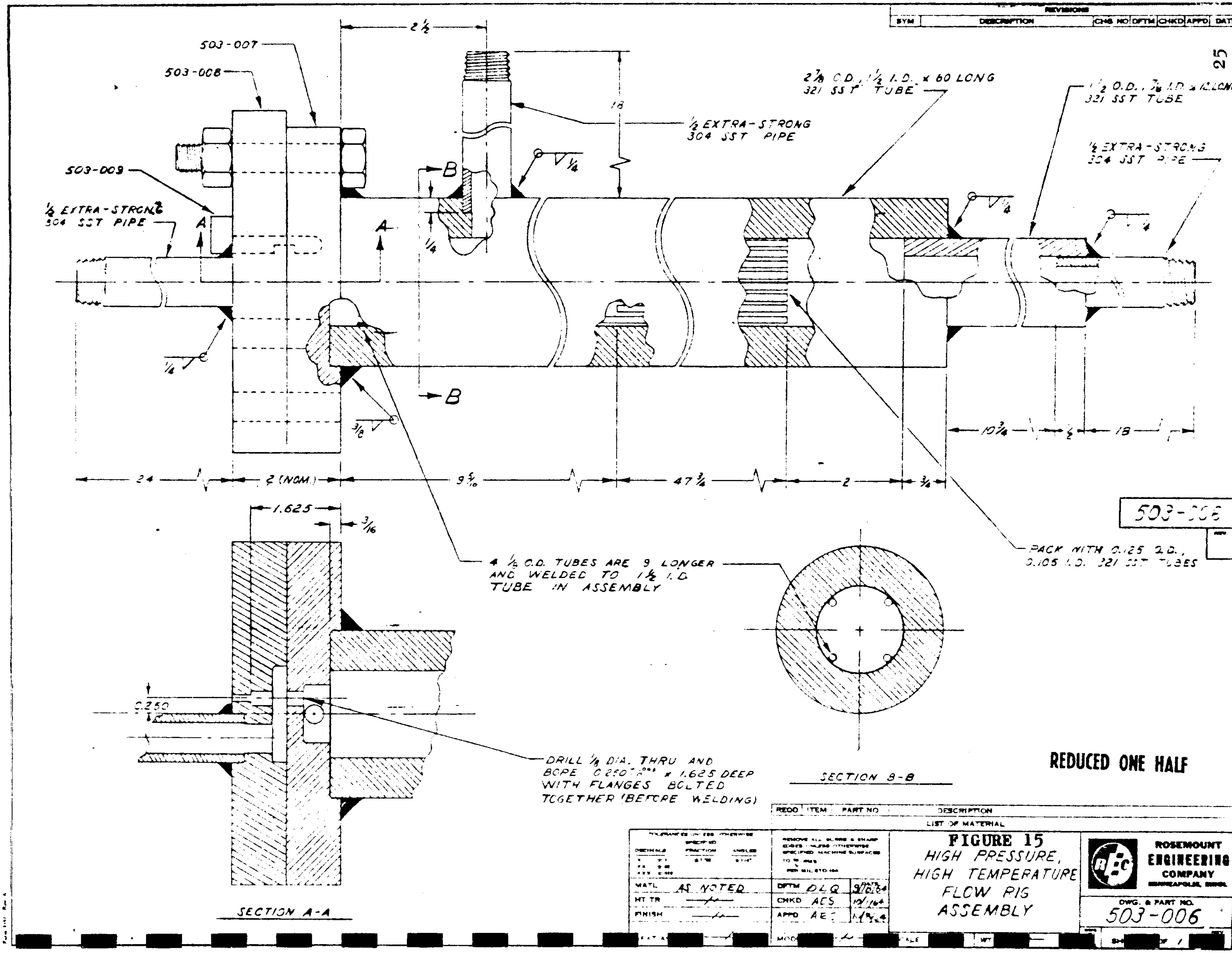
FIGURE 14
MOUNTING FLANGE FOR 117B HIGH TEMP, HIGH PRESSURE FLOW RIG

ROSEMOUNT ENGINEERING COMPANY

MODEL 117B

SCALE NONE

SHEET 1 OF 1


REVISIONS
SYM | DESCRIPTION | CHG NO | DFTM | CHKD | APPD | DATE
503-007
503-008
503-009
½ EXTRA-STRONG 304 SST PIPE
2½
18
½ EXTRA-STRONG 304 SST PIPE
2⅞ O.D., 1½ I.D. x 60 LONG 321 SST TUBE
1½ O.D., ⅞ I.D. x 12 LONG 321 SST TUBE
½ EXTRA-STRONG 304 SST PIPE
A
B
¼
⅜
10¾
½
18
24
2 (NOM.)
9 5/16
47¾
2
¾
503-006
PACK WITH 0.125 O.D., 0.105 I.D. 321 SST TUBES
1.625
3/16
4 ½ O.D. TUBES ARE 9 LONGER AND WELDED TO 1½ I.D. TUBE IN ASSEMBLY
0.250
DRILL ⅛ DIA. THRU AND BORE 0.250 x 1.625 DEEP WITH FLANGES BOLTED TOGETHER (BEFORE WELDING)
SECTION B-B
SECTION A-A
REDUCED ONE HALF
REQD | ITEM | PART NO | DESCRIPTION
LIST OF MATERIAL
MATL AS NOTED
HT TR
FINISH
DFTM DLQ
CHKD ACS
APPD AE
FIGURE 15
HIGH PRESSURE, HIGH TEMPERATURE FLOW RIG ASSEMBLY
ROSEMOUNT ENGINEERING COMPANY
DWG. & PART NO.
503-006

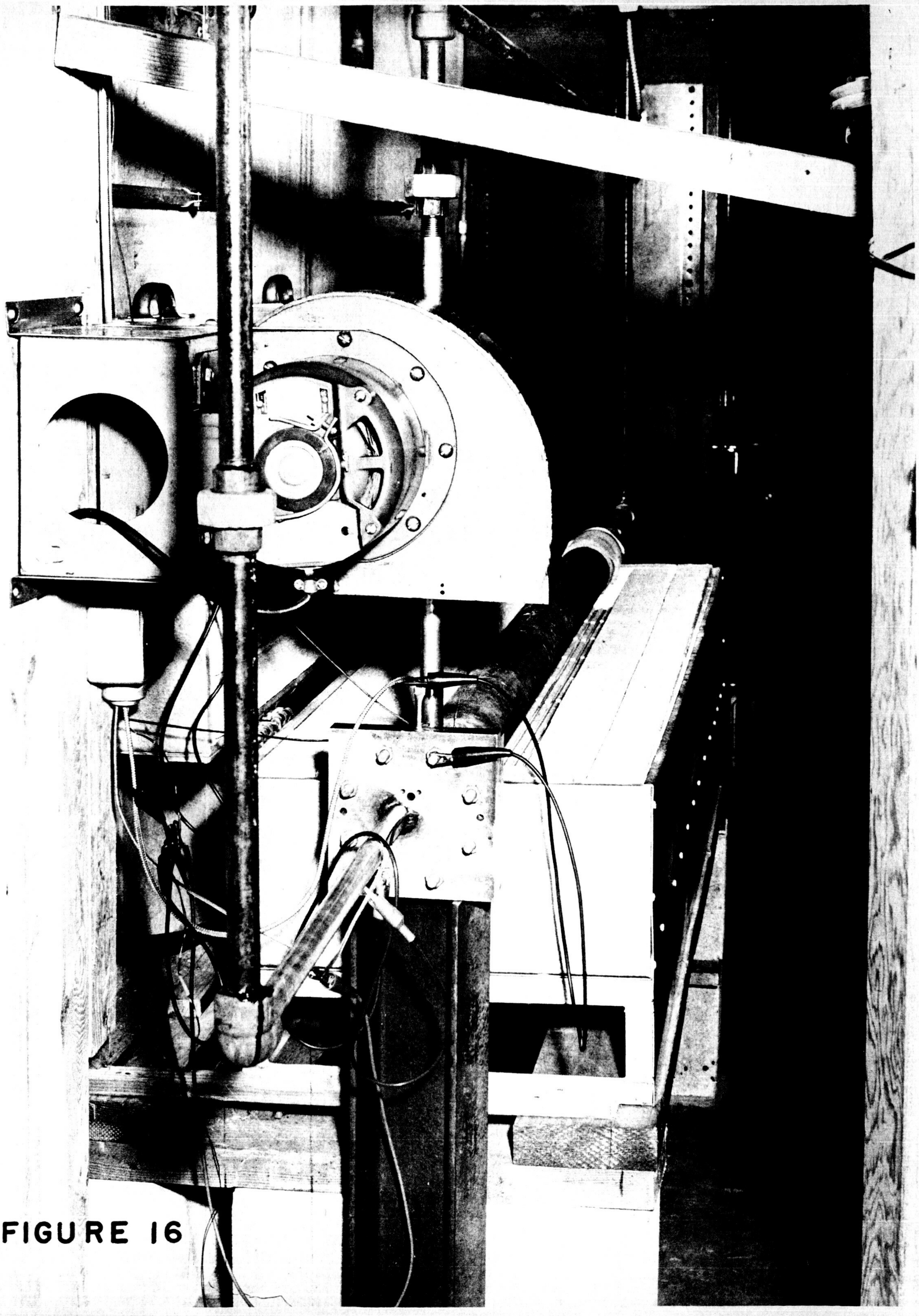


FIGURE 16

FIGURE 17

FIGURE 18

COMPARISON OF TIME RESPONSE FOR "PRE-BREADBOARD" AND INITIAL BREADBOARD TEMPERATURE GAGE DESIGNS,

NASA CONTRACT NAS8-11699

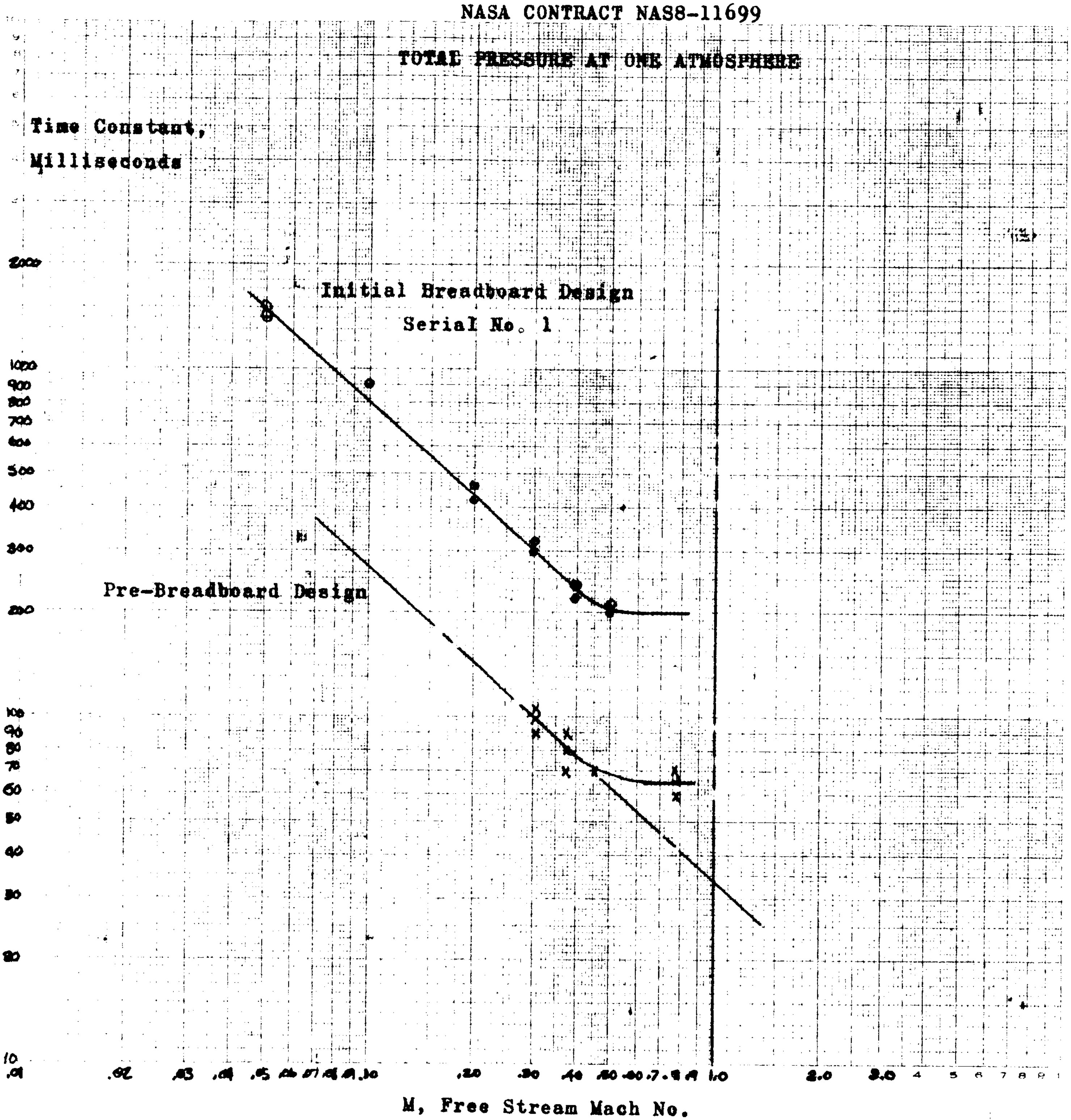


FIGURE 19

COMPARISON OF SERIAL NUMBER 4 GAGE TIME RESPONSE WITH MODEL 103H BARE WIRE THERMOELEMENT TIME RESPONSE FOR SUPERCRITICAL INLET TO OUTLET PRESSURE RATIO

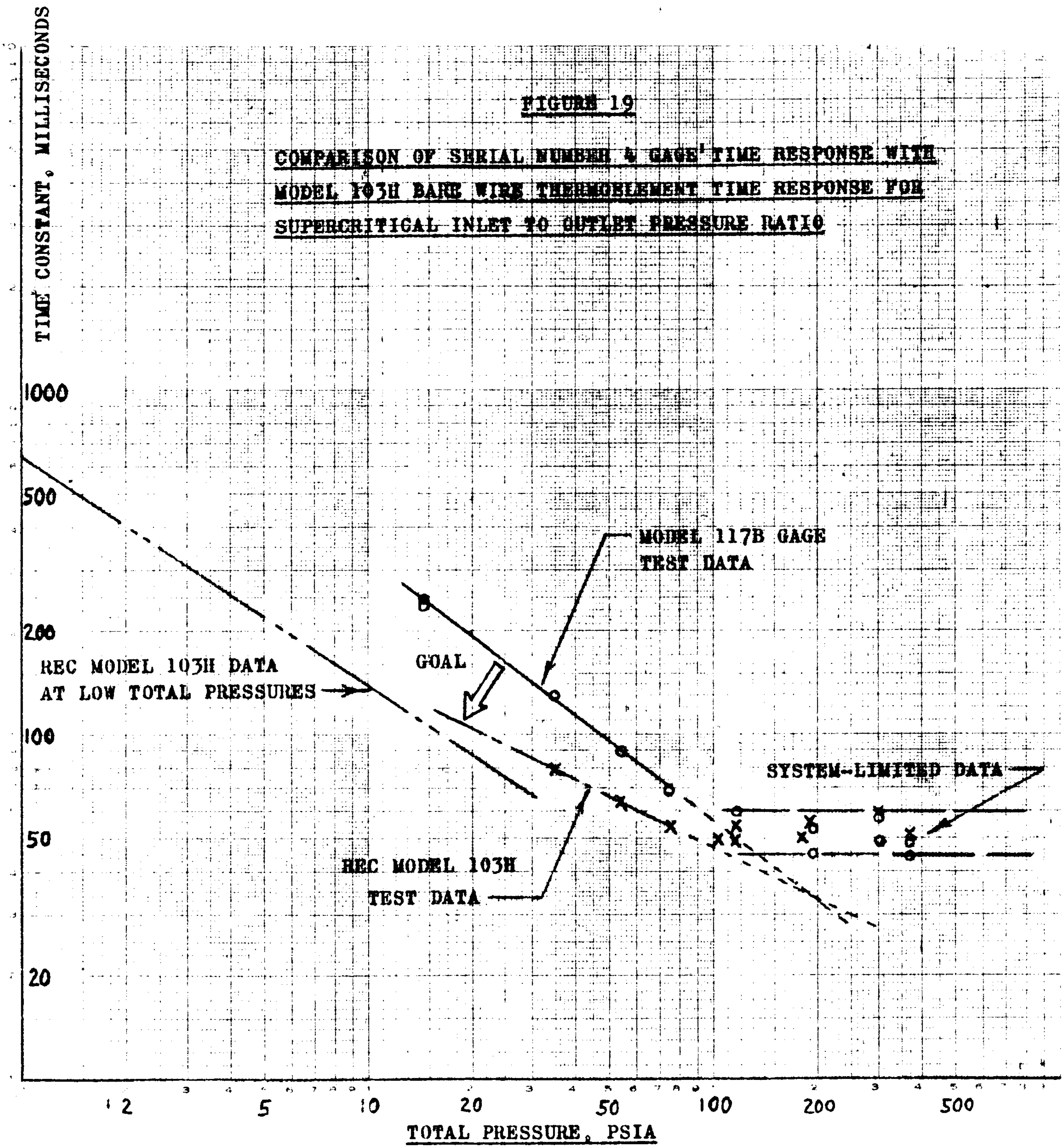
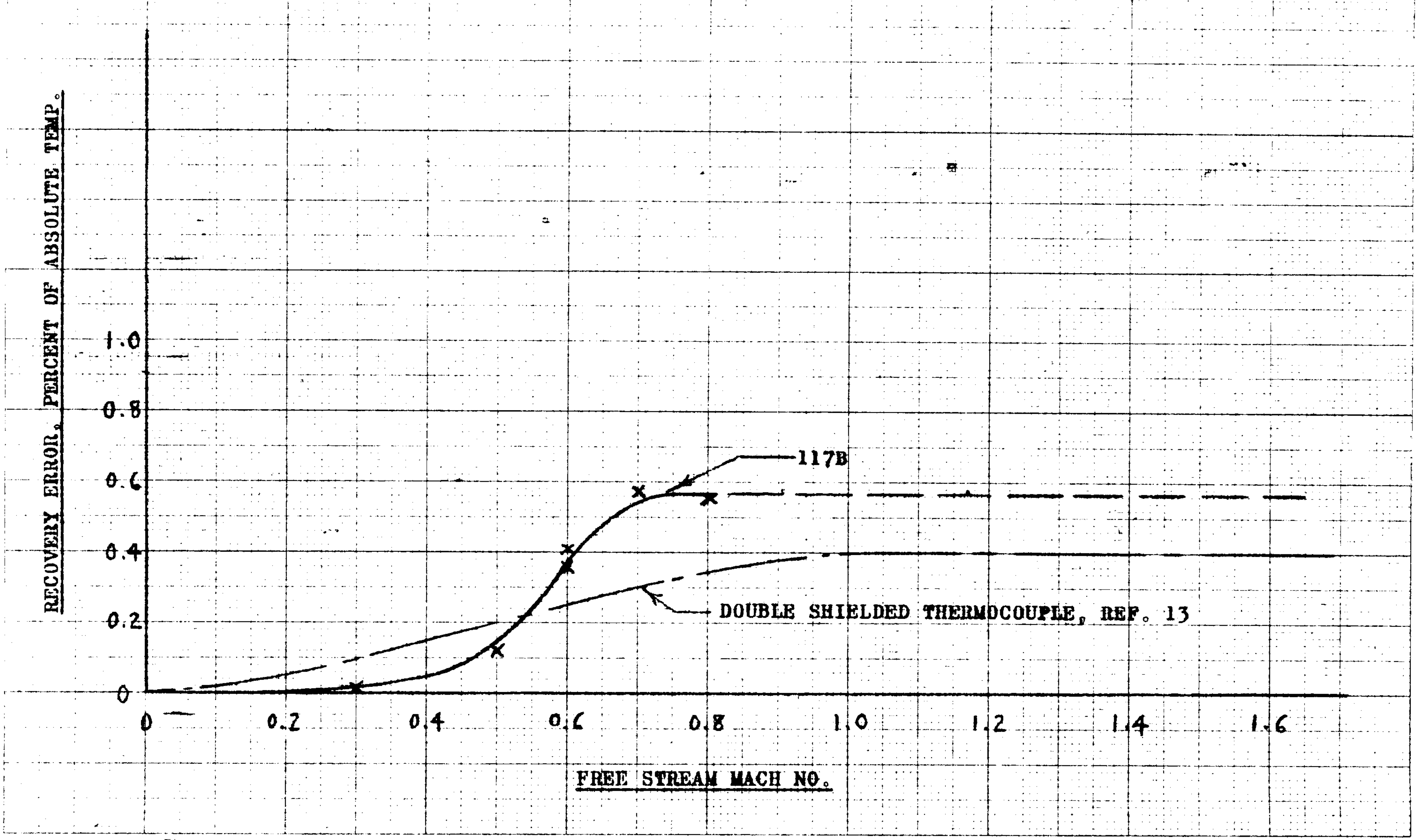


FIGURE 20

RECOVERY ERROR OF MODEL 117B TEMPERATURE GAGE

-20°C TO 80°C



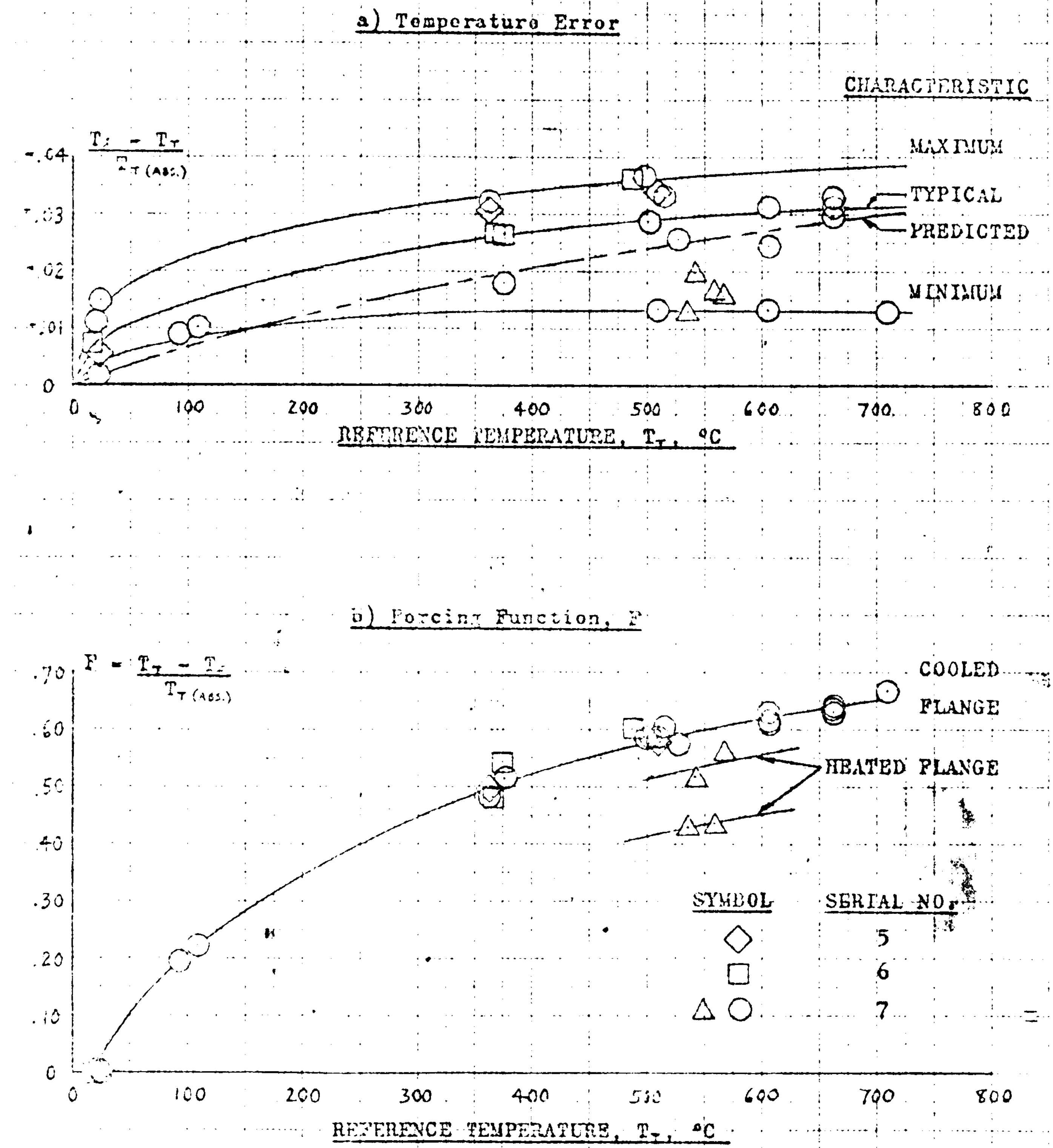


FIG. 21: EFFECT OF TEMPERATURE AT 70 PSIG PRESSURE ON MODEL 117B GAGE;
REC PROCEDURE NO. 16527 , SEC. 2 , CONDITIONS 1, 3, and 5

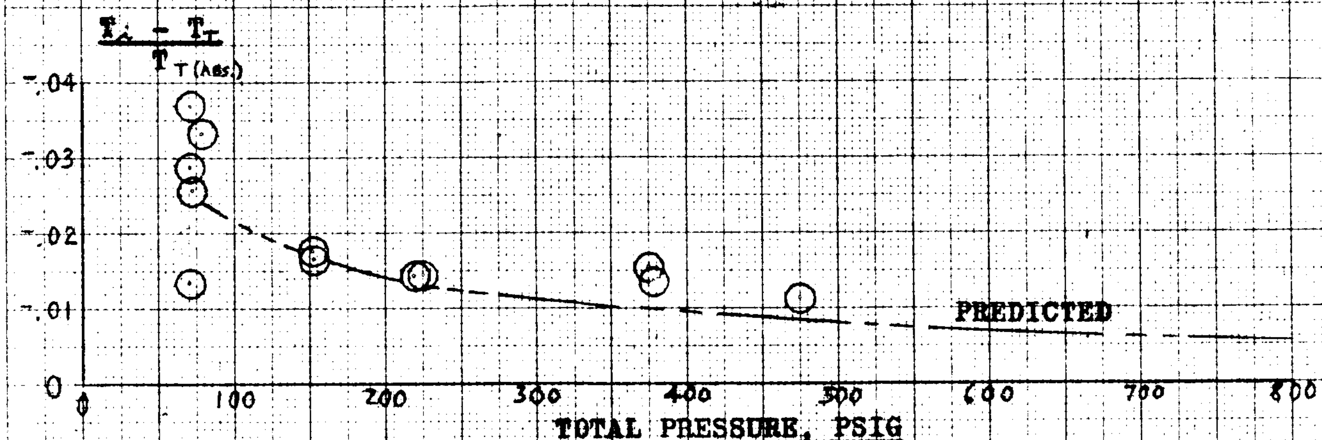


FIG. 22: EFFECT OF PRESSURE AT CONSTANT TEMPERATURE FOR MODEL 117B GAGE; REC PROCEDURE NO. 16527, SEC. 2, CONDITION 2, 540°C TEMPERATURE

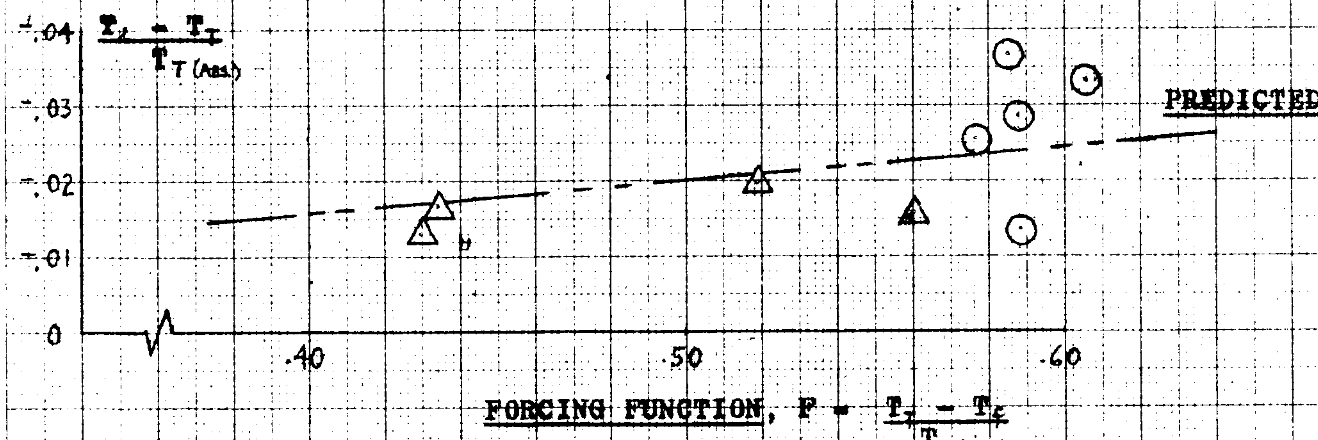


FIG. 23: EFFECT OF FLANGE TEMPERATURE AT 70 PSIG PRESSURE FOR MODEL 117B; REC PROCEDURE 16527, SEC. 2, CONDITION 3, 540°C TEMPERATURE

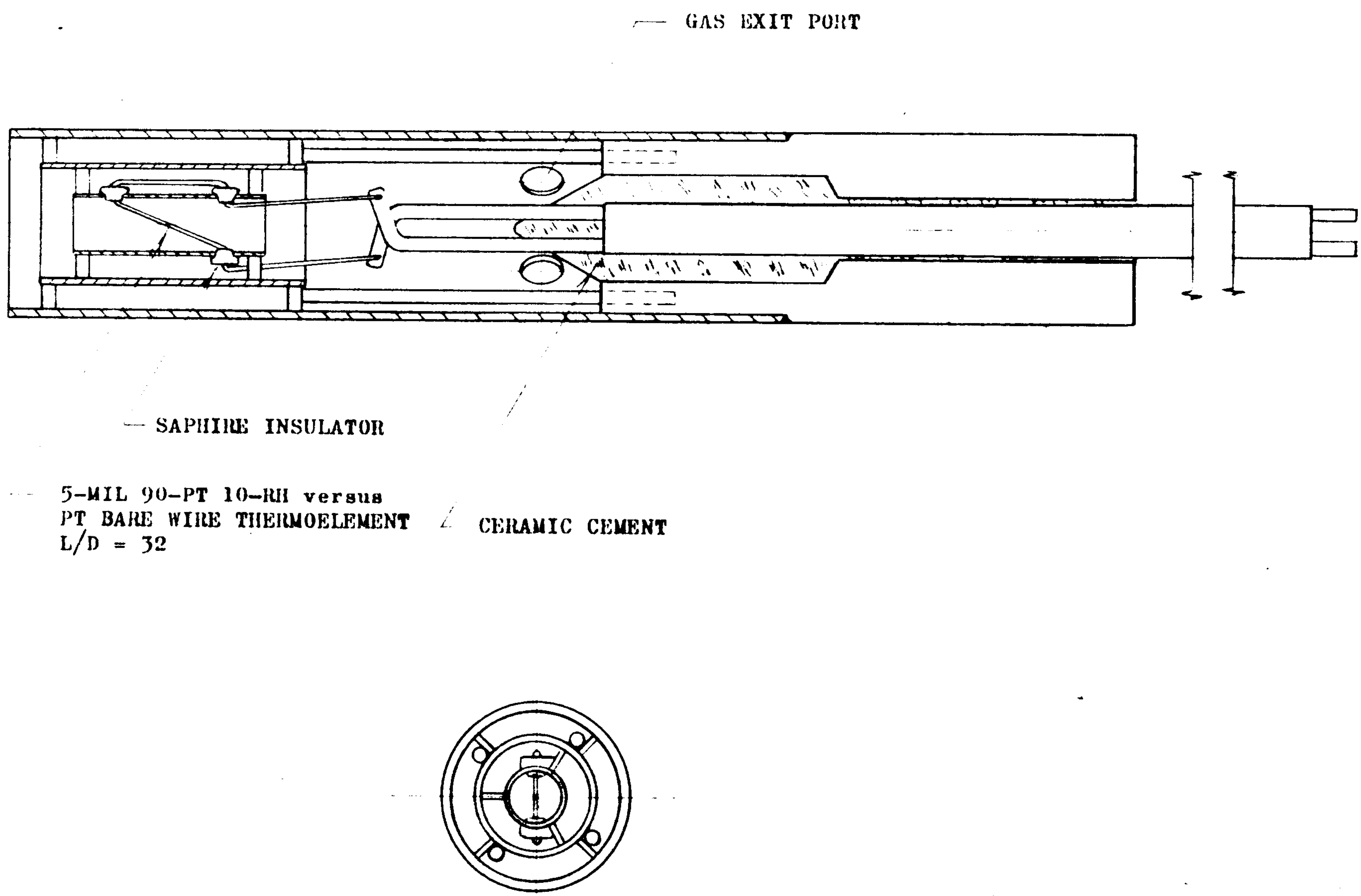


FIGURE 24: REC MODEL 103H REFERENCE SENSOR

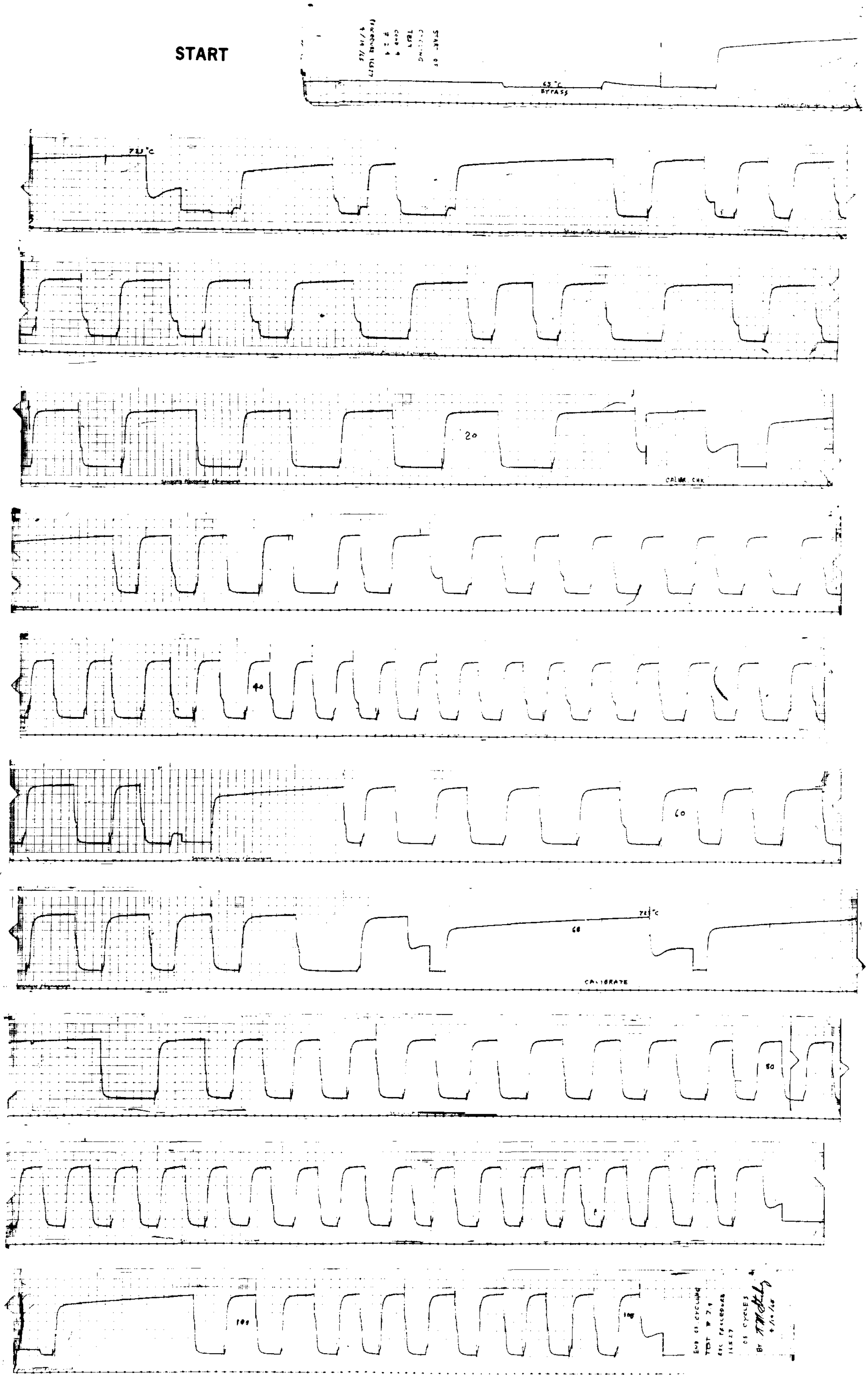
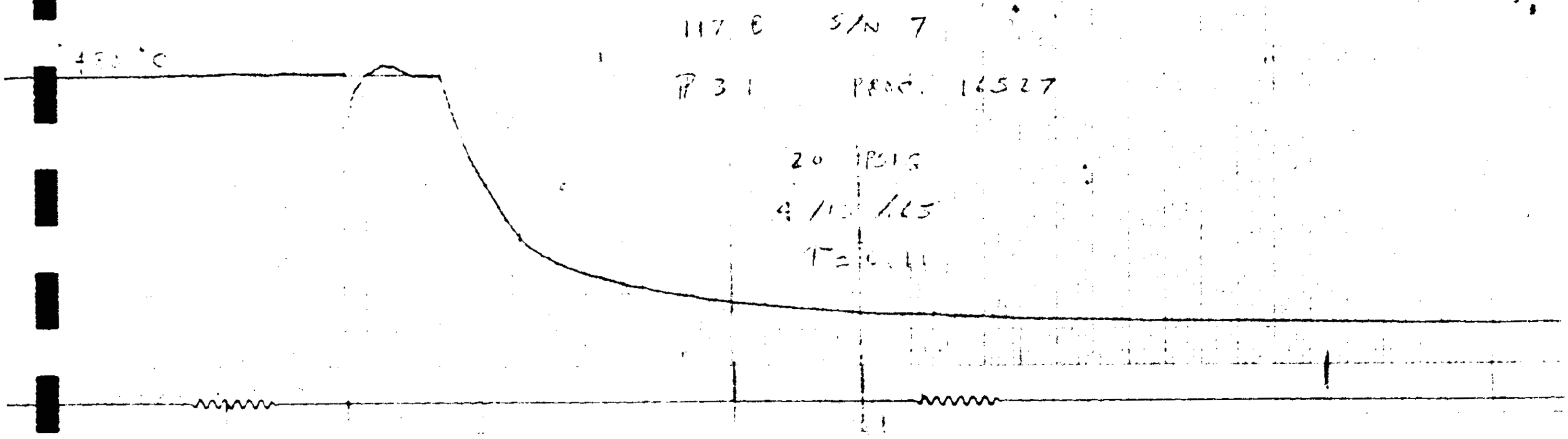
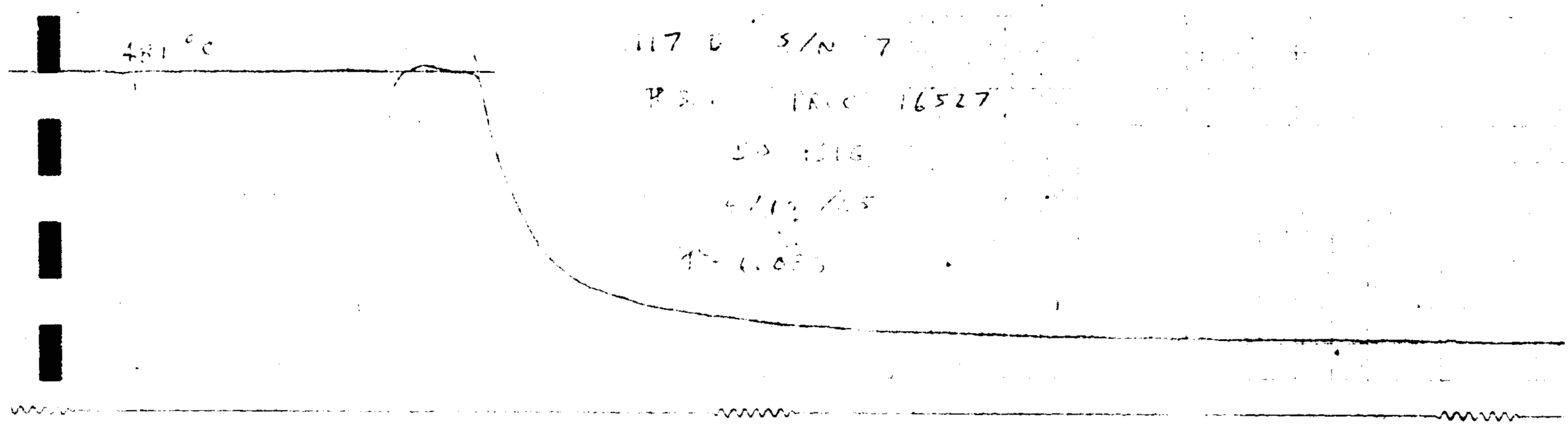


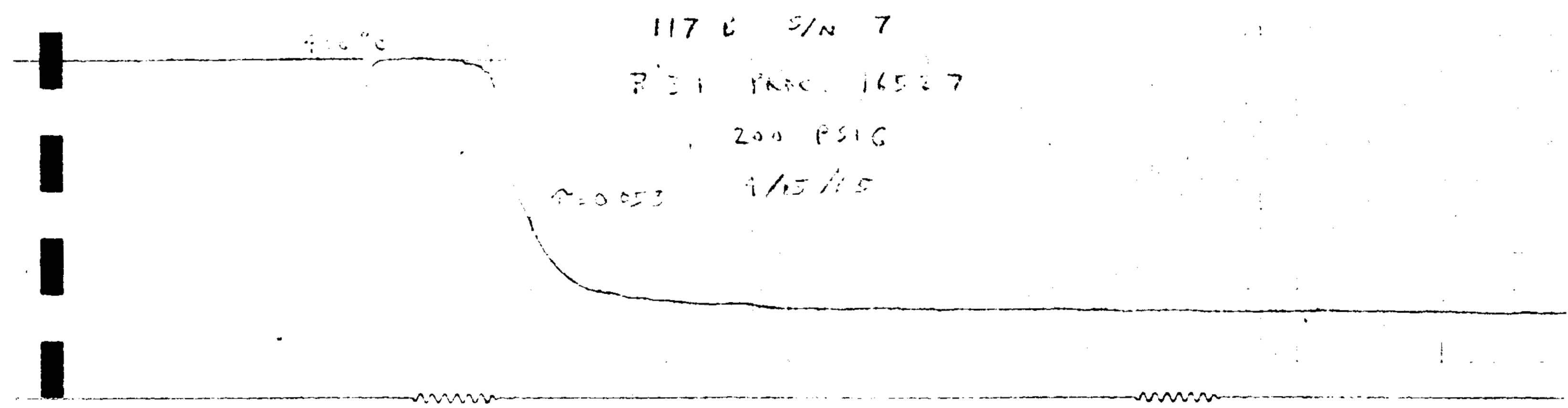
FIG 25 CYCLING TEST



20 PSIG Nitrogen Gas Pressure



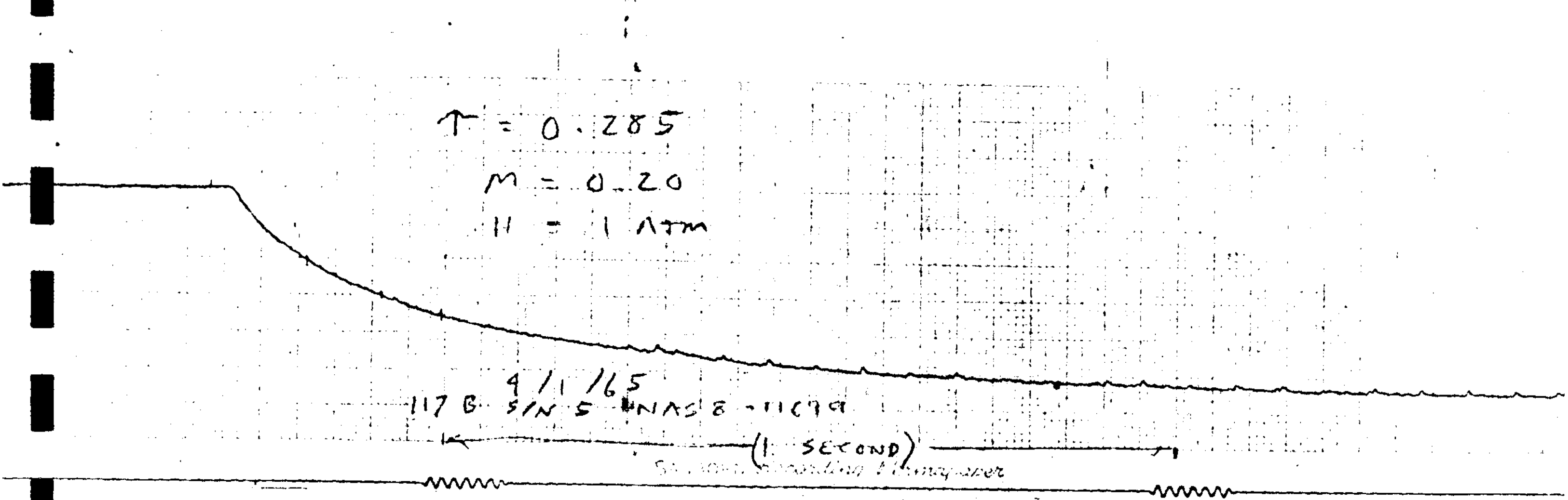
50 PSIG Nitrogen Gas Pressure



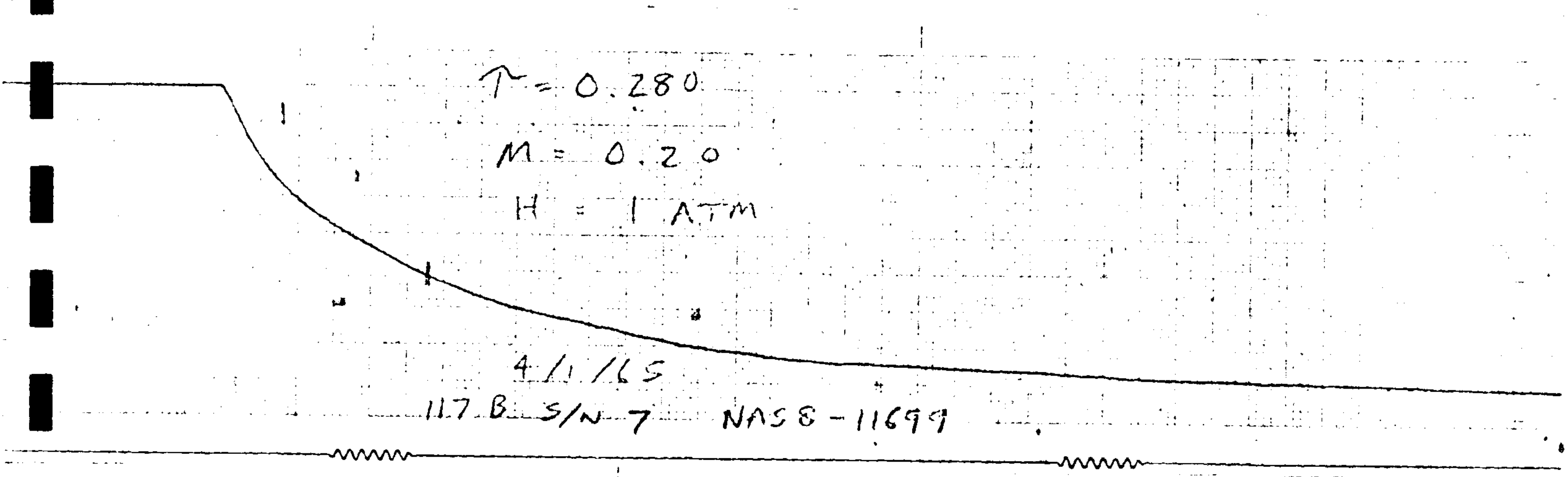
200 PSIG Nitrogen Gas Pressure

FIGURE 26

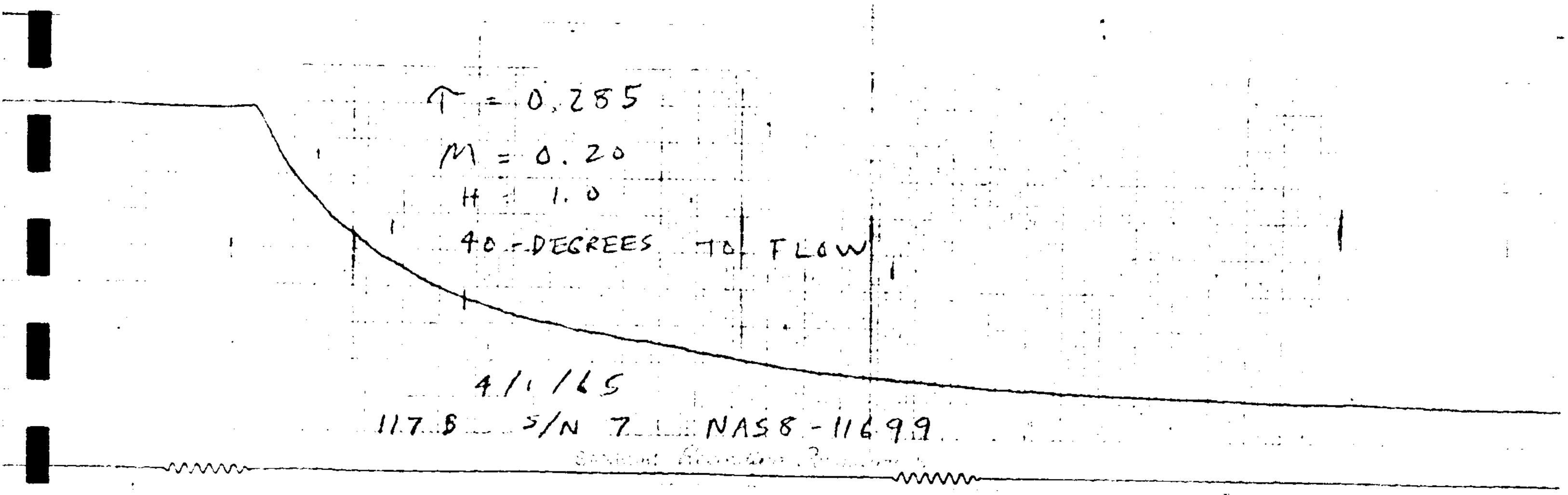
Time Response of 117B Temperature Gage at Three High Weight Flow Conditions, REC Procedure 16527, Sec. 3.1



Serial No. 5, Zero Angle



Serial No. 7, Zero Angle



Serial No. 7, 40 Degrees to Flow

FIGURE 27

Time Response of 117B Temperature Gage at Low Weight Flow Condition, 0.2 Mach No., Atmospheric Pressure, REC Procedure 16527, Sec. 3.2

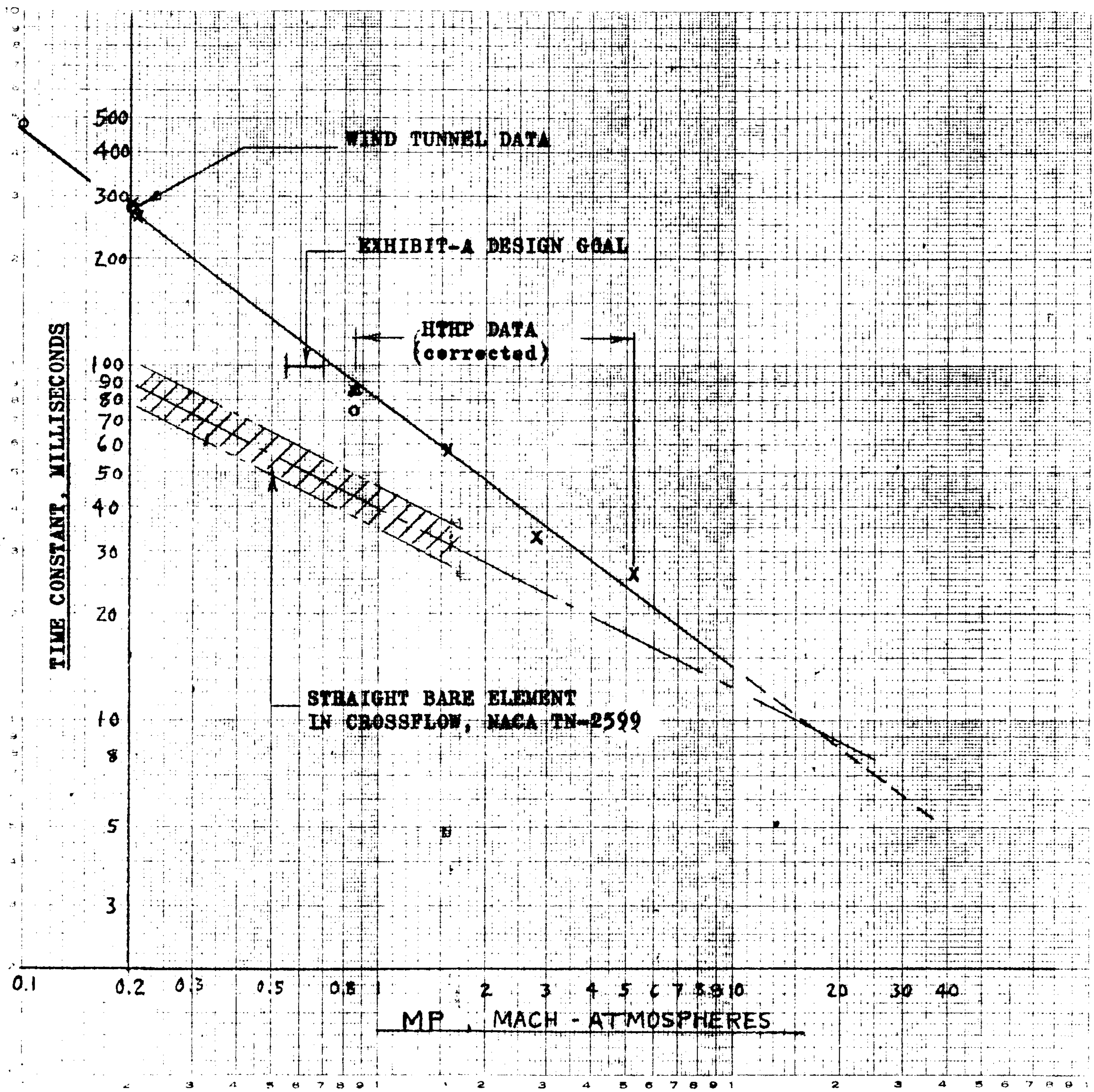


FIG. 28: CORRELATION OF 117B TEMPERATURE GAGE RESPONSE DATA

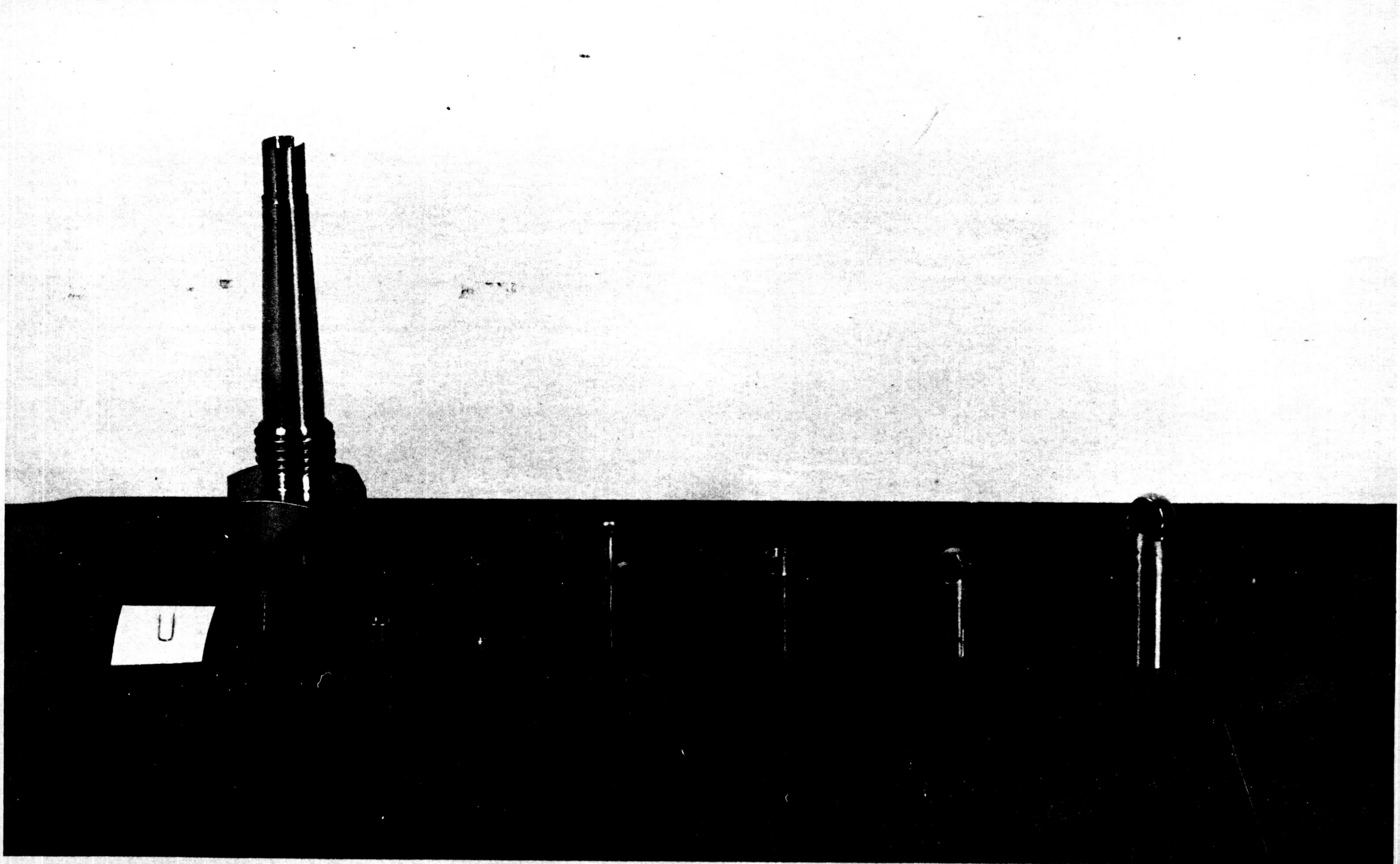


FIGURE 29

TABLE I

METHODS AND MATERIALS CONSIDERED IN THE DESIGN OF THE REC MODEL 117B TEMPERATURE GAGE

NASA CONTRACT NAS8-11699

USE OF:	CONTRIBUTES TO REALIZATION OF REQUIRED: STRENGTH	CORROSION RESISTANCE	PRESSURE SEALING	READING ACCURACY	FAST RESPONSE
Bare T/C Sensing Element	Yes	No	No	Yes	Yes
Glass Coated Sensing Element	No	Yes	No	No	---*
Noble Metal Sheathed Coax Sensing Element	Yes	Yes	Yes	---*	Yes
Uncoated Refractory Metal Housing	Yes	No	---	---	Yes
Coated Refractory Metal Housing	Yes & No	Yes	No	---	Yes
Noble Metal Housing	No	Yes	Yes	---	Yes
Stainless Steel Housing	No	Yes	Yes	---	No
Nickel-Base "Super Alloy" Housing	Yes	Yes	Yes	---	---
Glass Coated "Super Alloy" Housing	---	Yes	---	---	---
Graphite or Boron Nitride Housing	Yes & No	---	No	---	Yes
Ceramic-Glass Hermetic Seals	No	---	Yes	No	---
Continuous Thermocouple Wire Circuit Using Welded Metallic Barrier Type Seals	Yes	---	Yes	Yes	---
Welded Two-Piece Main Housing and Mounting Assembly	---	No	---	---	---
One-Piece Main Housing and Mounting Part	Yes	Yes	Yes	---	---
Flexible Fiber Covered Copper Alloy Lead Wires	Yes	No	---	No	---
Nickel Sheathed Plat.-Rhodium Lead Wires	Yes	Yes	Yes	Yes	---

*Note: A dash indicates either "Little Effect" or "Effect Unknown"

TABLE II

STRESSES IN GAGE STEM AT MAXIMUM AERODYNAMIC LOADING FOR FULLY DEVELOPED TURBULENT FLOW AT 815 PSIA PRESSURE

Station	X/R*	Applied Stress, PSI	0.2% Yield Stress, PSI	Safety Factor
1	0	20,900	35,300	1.69
2	1/8	15,150	34,100	2.25
3	1/4	8,700	33,800	3.88
4	3/8	1,770	33,600	19.0

* X = Distance from pipe inner wall into flow
R = Inner radius of pipe

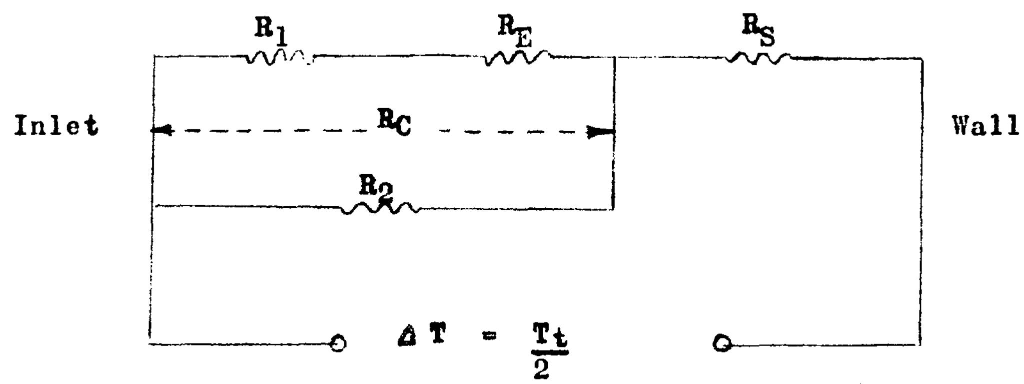
TABLE III

COMPUTATION OF ESTIMATED TIME CONSTANT FOR 8.5 MIL ELEMENT OF SOLID WIRE AND COAXIAL DESIGNS, AND EFFECT OF DIAMETER TOLERANCE ON TIME CONSTANT

Parameter	Solid	Co-Ax
Mass Velocity, lbs./ft.^{2} second	45.7	45.7
Reynolds Number	2660	2660
Mach-Atmosphere Product	.684	.684
Density-Specific Heat Product	44.0	40.0
Time Constant of Long Wire at 200°C	.052	.047
Empirical Form Factor	1.33	1.33
Estimated Nominal Time Constant, Second	.069	.063
One-Mil Undersize Factor	.830	.830
One-Mil Oversize Factor	1.182	1.182
Lower Limit Time Constant, Second	.057	.052
Upper Limit Time Constant, Second	.081	.074
Time Constant Tolerance, Second	±.012	±.011
Specified Nominal Time Constant, Second	.100	.100
Minimum Allowable Effect of Shields, Second	.019	.026

TABLE IV

ELECTRICAL ANALOG COMPUTATION OF CONDUCTION ERROR FOR THREE TEMPERATURES AT A TOTAL PRESSURE OF 225 PSIG ASSUMING SUPERCRITICAL INLET TO OUTLET PRESSURE RATIO



PARAMETER	TEMPERATURE, T_T, °C		
	100	540	800
1. Element Reynolds No.	2930	1980	1730
2. Element Nusselt No.	25.7	21.4	20.3
3. Element Convective Heat Transfer Co-Efficient	.321	.267	.254
4. Element Thermal B/L Resistance, °C/watt, R_1	1210	1452	1526
5. Element and Support Wire Thermal Resistance, °C/watt, R_E	3810	3500	3350
6. Shields and Stem Thermal Resistance, °C/watt, R_S	1704	1505	1426
7. Inner Shield Reynolds No.	51,000	34,450	30,450
8. Inner Shield Nusselt No.	45.9	40.7	39.0
9. Inner Shield Convective Heat Transfer Co-Efficient	.0660	.0584	.0560
10. Inner Shield Thermal B/L Resistance, °C/watt, R_2	215	242	255
11. Total Thermal Resistance in Convective Zone, R_C	206	231	241
12. $R_C + R_S$, °C/watt	1910	1736	1667
13. $R_1 + R_E$, °C/watt	5020	4952	4876
14. ΔT, °C	50	270	400
15. $\Delta T_C = (11)(14)/(12)$, °C	5.4	36.9	57.8
16. Conduction Error = (4)(15)/(13), °C	1.3	10.8	18.1
17. % Conduction Error = (16)(100)/(2x(14)+273)	0.35	1.33	1.69

* Listed values of thermal resistance are a factor of Pi times as great as the true computed values. Pi cancels finally, so it is omitted in this tabulation.

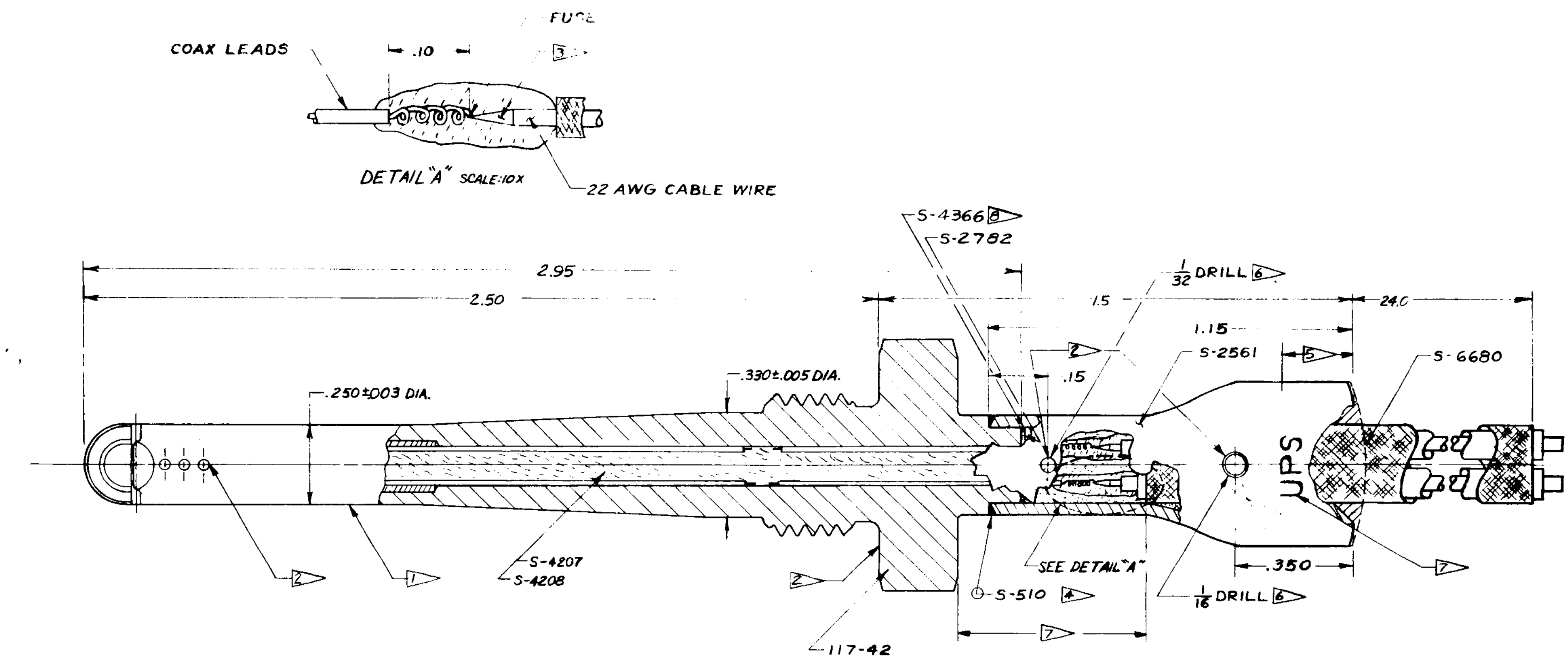
TABLE V

SUMMARY OF TEST RESULTS: 117B BREADBOARD GAGES, REC PROCEDURE 16527

		GAGE SERIAL NUMBER		
PARAGRAPH	CHARACTERISTIC	5	6	7
2.1	Percent Error, 760°C, 70 PSIG	–	–	-3.8
	* NORMALIZED ERROR, (percent)	–	–	-2.8
2.2	Percent Error, 540°C, 150 PSIG	–	–	-1.7
	Percent Error, 540°C, 225 PSIG	–	–	-1.4
	Normalized Error at 150 PSIG	–	–	-1.4
	Normalized Error at 225 PSIG	–	–	-1.2
2.3	Percent Error at F=0.43, 70 PSIG	–	–	-1.7
	Normalized Error at F=0.50, 70 PSIG	–	–	-2.0
2.4	Cycling Test Cycles	–	–	108
2 & 3	Total No. of Heating Cycles	30	11	125
2.5	% Deviation From Mean, 370°C	+0.1	-0.3	+0.2
	% Deviation From Mean, 500°C	-0.2	+0.1	+0.1
3.1	Time Constant, Seconds, 20 PSIG	.085	.075	.085
3.3	Time Constant, Seconds, 200 PSIG	–	–	.026
3.2	Time Constant, Seconds, M=0.2	.283	–	.275
4	P: Passed Vibration	–	P	–
5	P: Passed Leakage	P**	P	P
6	Initial Error, °C, 100°C	-.06	+.17	+.51
	Initial Error, °C, 300°C	+.11	+.07	+.40
	Final Error, °C, 100°C	+.30	-.40	0
	Final Error, °C, 300°C	0	0	+.30

* Maximum Percent Error Based on Forcing Function, F=0.50

** Serial Number 5 Gage passed Leakage following bulkhead repair



NOTES

1. FOR ASSEMBLY DETAILS SEE DRAWING 117-42.
2. CENTER LINE OF HOLES LOCATED PER AND-10050 FIXTURE T117-505 WITH MOUNTING SURFACE FINGER TIGHT AGAINST AND10050 SURFACE.
3. POINT ENDS OF CABLE WIRES. BE SURE THAT LIKE WIRES ARE ALIGNED BEFORE FUSING.
4. SOLDER BEFORE POTTING, OBSERVE NOTE 2.
5. PRESS TO SECURE CABLE. USE T-117-506 PRESSURE FIXTURE : 1/4 INCH NOM.
6. INSERT {S-4207, S-4208} THROUGH $\frac{1}{16}$ DIA. HOLE UNTIL EXCESS COMES OUT $\frac{1}{32}$ DIA. HOLE. CURE, WELD HOLES SHUT, AND CLEANUP.
7. ELECTROETCH IDENTIFICATION AND LETTERS "UPS" TO SHOW UPSTREAM DIRECTION.
8. BEFORE COMPLETING ASSEMBLY, SUBJECT UNIT TO HELIUM PRESSURE TEST AT 850 PSIG FOR FIVE MINUTES. REPAIR BULKHEAD SEAL IF LEAK OCCURS.
9. CALIBRATE AT 100°C AND 300°C IN AGITATED OIL BATH

QUANTITY REQD	PART NO	DESCRIPTION
A.R.	S-510	SOLDER, SILVALOY #250
A.R.	S-4208	BINDER, SAUEREISEN #29
A.R.	S-4207	FILLER, SAUEREISEN #29
A.R.	S-4366	SOLDER, 810F, 81% GOLD 1600°F,
A.R.	S-2842	SHEET, 90% Pt. 10% Rh. .010 THICK
25	S-6680	CABLE, 90% Pt. 10% Rh. VS. Pt. DUPLEX, GGS-22-P10
1 1/4"	S-2561	TUBING, 304 SST, 5/16 O.D. X .242 I.D.
1	117-42	FINAL PARTS ASSEMBLY

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED REMOVE ALL BURRS AND SHARP EDGES MACHINE SURFACE FINISH 125
TOLERANCES
DRILLED HOLES
.0135 to .125 +.004 −.001
.126 to .250 +.005 −.001
.251 to .500 +.006 −.001
DO NOT SCALE PRINT

ROSEMOUNT ENGINEERING COMPANY
MINNEAPOLIS, MINN.

TITLE
FINAL ASSEMBLY
117B

CODE IDENT NO	SIZE	DRAWING & PART NO	REV
04274		117-44	

SCALE 4X SHEET 1 OF 1

DRAWING & PART NO 117-44

SPECIFICATIONS

1. **SCOPE**: The Model 117B is a total temperature sensor developed for a specific application in a large boost vehicle plumbing system involving high pressure rocket gases. This rugged fast response sensor may be used for gas temperature measurements under near-neutral to oxidizing conditions over wide ranges of flow velocity, total pressure, temperature and flow angle.

2. **DESIGN AND PERFORMANCE SPECIFICATIONS**: The design and performance specifications are summarized below:

2.1. Temperature Limits: The maximum total temperature is defined by the graph which shows the variation along the length of the sensor. In general, the limiting curve falls above the steady-state temperature gradient in pipes and ducts of the size and length normally used in vehicle plumbing systems where centerline temperature is about 1000° C. For low weight flows, higher wall temperatures are allowable to a limit of 700° C.

2.2. Thermocouple Accuracy: The thermocouple output conforms to the temperature-emf relationship for platinum 10 percent rhodium versus platinum as described in NBS Circular #561 with reference junction corrections applied as required per NBS Circular #590, Paragraph 6. The allowable error is stated as follows:

2.2.1. -20° C to 200° C : ±1° C

2.2.2. 200° C to 1500° C : ±1/2 percent of indicated temperature (° C)

2.3. Time Response: The time constant shall be less than 150 milliseconds for 63 percent of a temperature step change at 0.6 to 5.0 Mach number and one standard atmosphere static pressure. The time constant shall be less than 40 milliseconds for the same Mach number range above 5 atmospheres static pressure. The points defining the typical line characteristic using logarithmic coordinates are (0.2, 300) and (25, 10) with the product of Mach number and pressure in atmospheres as the abscissa and the time constant in milliseconds as ordinate.

2.4. Accuracy: The nominal thermodynamic error in the measurement of total temperature (absolute units) is:

		*MP = 1	MP = 3	MP = 30
2.4.1.	-20° C to 100° C :	-1 percent	-1/2 percent	-1/8 percent
2.4.2.	200° C :	-2 percent	-1 percent	-1/4 percent
2.4.3.	400° C :	-3 1/2 percent	-2 percent	-1/2 percent
2.4.4.	700° C :	-5 percent	-3 percent	-3/4 percent
2.4.5.	1300° C :	-7 1/2 percent	-4 1/2 percent	-1 1/2 percent

* (Parameter is given as Mach number times static pressure in Mach-Atmospheres. The more accurate but less convenient parameter includes the inverse square root of temperature.)

2.4.6. The above errors are based on wall temperature equal to approximately 1/2 indicated temperature, (° C).

2.5. Flow Angle: The time response (2.3) and accuracy (2.4) specifications are applicable for angle of attack or sideslip up to twenty degrees in a uniform flow field.

2.6. Vibration: The 117B temperature sensor withstands thirty minutes of cycling between 700 and 2000 cycles sine wave input at 35 G's peak with 20-2000 cycles per second random excitation at $1.0\,G^2$/cps superimposed at normal room ambient conditions.

2.7. Diffusion: When pressurized with helium at 800 psig and 800° C (maximum temperature for Zone C as shown in graph), the gas leakage through the gage shall be less than one cubic centimeter per minute for a thirty minute period.

2.8. Mounting: Each 117B sensor is fabricated such that the inlet centerline and the letters UPS indicating UPSTREAM direction are aligned with a scribe line on a standard AN-893-3S (AND-10050) mounting boss. Insuring correct alignment to flow by proper orientation of the user's mounting boss is an important requirement, (2.5), but must be considered as a user responsibility.

2.9. Static Load: The 117B sensor is functional during and after the application of a 250 pound static load at a point one inch up from the face of the MS 33656-4 mounting with the temperature gradient as specified by the graph.

3. **IDENTIFICATION DATA**: Identification data shall be electroetched in the area shown and shall include the following:

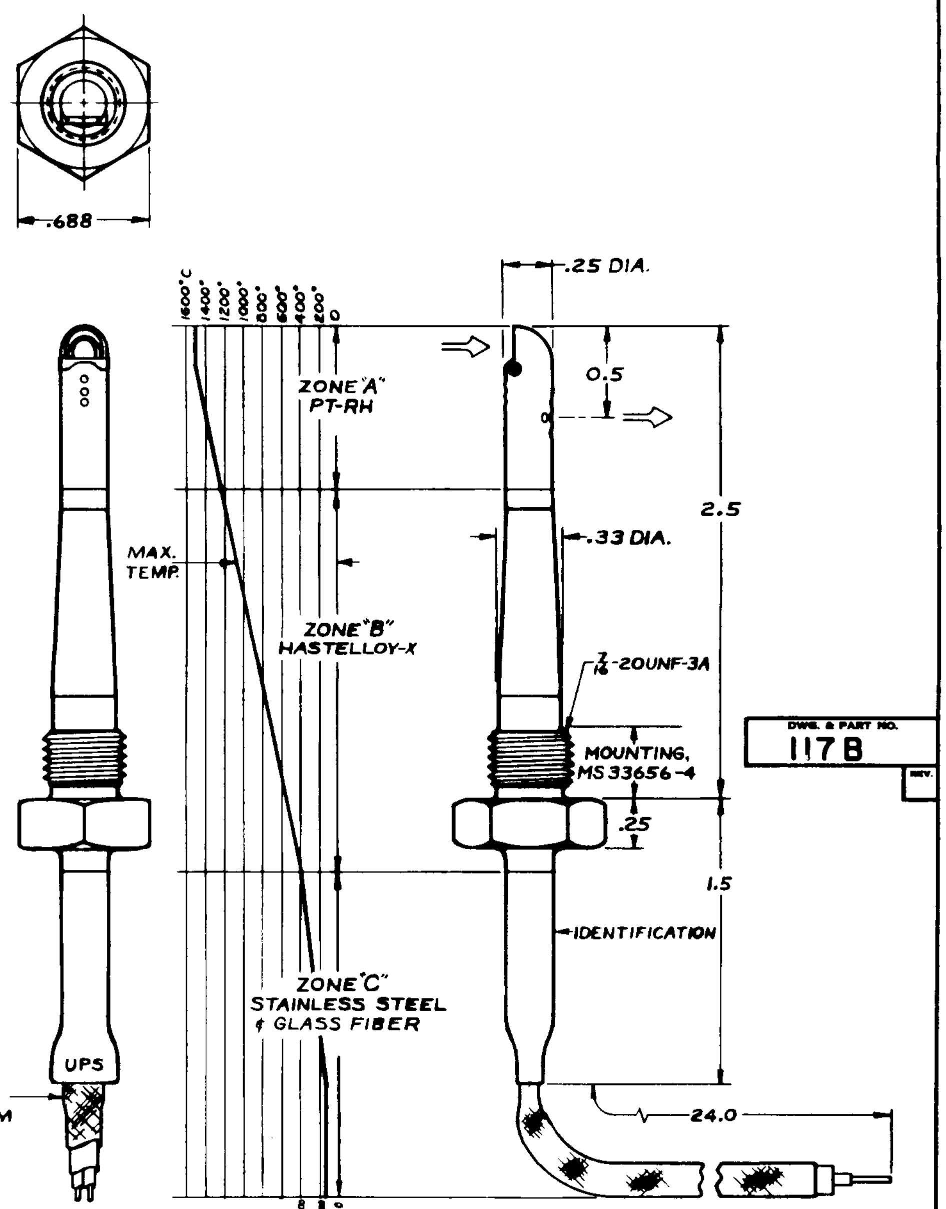
SENSOR, TOTAL TEMPERATURE
MODEL 117B S/N ____________
ROSEMOUNT ENGINEERING COMPANY
(Government Contract No. if applicable)

4. **INDIVIDUAL TESTS**: Individual tests to be performed on each sensor shall include the following:

4.1. Examination of Product: Each sensor shall be inspected to determine conformance to this drawing with respect to component parts, workmanship and marking.

4.2. In-Process Leakage Test: Before final assembly in Zone C is completed, each unit shall be subjected to 850 psig helium pressure at room temperature for a period of 5 minutes with no indication of leakage through the gage as determined by soap bubble test. A travel card must show successful completion of this test for final inspection approval.

4.3. Thermocouple Calibration: Test data must indicate conformance to Paragraph 2.2. above using equipment and procedures comparable to those outlined in NBS Circular #590.



SYM | DESCRIPTION | CHG NO | DFTM | CHKD | APPD | DATE — REVISIONS

DWG. & PART NO. 117 B — REV.

NASA CONTRACT NO. NAS8-11699

TOLERANCES UNLESS OTHERWISE SPECIFIED
DECIMALS .X ± .1, .XX ± .02, .XXX ± .010 — FRACTION ± 1/32 — ANGLES ± 1/4

REMOVE ALL BURRS & SHARP EDGES UNLESS OTHERWISE SPECIFIED; MACHINE SURFACES TO 125 RMS PER MIL-STD-10A

MATL — HT TR — FINISH — NEXT ASSY

REQD | ITEM | PART NO | DESCRIPTION — LIST OF MATERIAL

DFTM THORSFELDT 8-6-64
CHKD [signature] 4/14/65
APPD [signature] 4/14/65
MODEL 117B

SPECIFICATION DRAWING
SENSOR, TOTAL TEMPERATURE
THERMOCOUPLE, 90% PLATINUM-10% RHODIUM VS. PLATINUM

SCALE 2X — WT

MFR 04274
ROSEMOUNT ENGINEERING COMPANY MINNEAPOLIS MINN.
DWG. & PART NO. 117 B
SIZE C — SHEET 1 OF 1 — REV.

environ

9725 Girard Avenue South
Minneapolis, Minnesota 55431

ENGINEERING REPORT NO. 1275-36

"VIBRATION TESTING"

12 April 196[illegible]

for

ROSEMOUNT ENGINEERING COMPANY
4900 West 78th Street
Minneapolis, Minnesota

Prepared by: Robert I. Meyer
Associate Environmental Engineer

William T. Docherty
Vice President

ENVIRON LABORATORIES, INC. | ENGINEERING REPORT NO. [illegible]
12 April 1965 | Page 1

Prepared for: ROSEMOUNT ENGINEERING COMPANY
4900 West 78th Street
Minneapolis, Minnesota

Subject: VIBRATION TESTING

1. ABSTRACT

One (1) Model 117B Temperature Gage Breadboard Unit was [illegible] to the vibration schedule outlined in Paragraph 4 of R.E.C. Test Procedure No. 16527.

The unit was vibrated in two (2) axes. No discontinuities were noted and the unit appeared to be satisfactory at the completion of [illegible].

2. UNIT TESTED

One (1) Rosemount Engineering Company Model 117B Temperature Gage Breadboard Unit identified by Serial Number 6 and submitted for testing by Rosemount Engineering Company, Minneapolis, Minnesota.

3. TEST REQUESTED

Conduct a vibration test per Paragraph 4 of R.E.C. Test Procedure No. 16527 which states:

One of the breadboard gages shall be vibrated along [illegible] coordinate axes [illegible] normal to the gage axis. The gage shall be subjected to fifteen minutes of cycling between 700 and 2000 cycles per second sine wave input at 35 g's peak with 20-2000 cycles per second random excitation at 1.0 g^2/cps superimposed for each of the above two axes. The gage output leads shall be monitored for continuity and insulation breakdown at approximately [illegible] VDC applied voltage during the entire 30 minutes of vibration testing.

4. INSTRUMENTATION

M-B Model C-50 Shaker
M-B Model T-88 Vibration Control Console with parallel filter [illegible]
M-B Model T-665 Amplifier
Endevco Model 2226 Accelerometer
Endevco Model 2614B Amplifier

5. PROCEDURE AND RESULTS

5.1 Equalization

Equalization was accomplished by adjusting each of the eighty (80) parallel filters to obtain a flat response. The random signal was used for excitation.

5.2 Testing of the Unit

The unit was vibrated in each of the two (2) axes with a 35 g peak [illegible] sine wave signal, between 700 cps and 2000 cps, applied simultaneously with a [illegible] g rms random signal between the frequency limits of 20 [illegible] for a period of fifteen (15) minutes in each axis.

5. PROCEDURE AND RESULTS (Continued)

5.2 Testing of the Unit (Continued)

During each of the vibration runs, the unit was continually monitored and no discontinuities were noted. Upon completion of the test, the unit was visually examined and it appeared to be satisfactory. The unit was returned to Rosemount Engineering Company for post vibration evaluation.

6. WITNESSING PERSONNEL

Mr. Ron Johansen of Rosemount Engineering Company witnessed this test.

ROSEMOUNT ENGINEERING COMPANY

4900 WEST 78th St

PHONE 927 7711

MINNEAPOLIS 24 MINN

TWX MP1093

TEST PROCEDURE FOR REC MODEL 117B TEMPERATURE GAGE BREADBOARD UNITS: NASA CONTRACT NAS8-11699

REC Test Procedure 16527

TEST PROCEDURE FOR REC MODEL 117B TEMPERATURE GAGE
BREADBOARD UNITS: NASA CONTRACT NAS8-11699
REC Test Procedure 16527

REFERENCE 1: NASA Exhibit A Scope of Work: Contract NAS8-11699

REFERENCE 2: Technical Proposal for the Development of a High Temperature Gage for High Velocity Flow in a Vehicle Plumbing System, per MSFC Exhibit A, RFQ 1-4-40-01170, REC Proposal 5647A.

REFERENCE 3: August 1964 Progress Report under NAS8-11699, REC Report 96411H.

REFERENCE 4: September 1964 report under contract NAS8-11699, REC Report 106414A.

1. SCOPE: It is the purpose of this document to specify tests to be conducted on three breadboard model 117B gages to be furnished to NASA under subject contract. High temperature performance test procedures utilize the HTHP test apparatus described in reference 3 and 4 primarily. Proposed tests are generally in conformance with reference 2, section 5.1. The proposed tests meet the requirements of section E of reference 1 and are for the purpose of establishing gage performance according to the design guidelines of section B of reference 1.

2. EVALUATION OF COMBINED RADIATION AND CONDUCTION ERRORS: One 117B breadboard gage shall be mounted in the HTHP test apparatus described in references 3 and 4 and subjected to test conditions 1 through 5 below. Measurements shall be obtained for the test gage output, the reference sensor output, the test pressure, and a mounting flange temperature.

2.1 Condition 1: With pressure stabilized at approximately 70 psig and mounting flange maintained at near room temperature values, the gas temperature shall be set approximately at the following levels: 20°C (68°F), 100°C (212°F), 400°C (752°F), 540°C (1004°F), 660°C (1220°F), 760°C (1400°F). Error in the output of the test gage shall be determined under these conditions.

2.2 Condition 2: With gas temperature set at approximately 540°C (1004°F) and mounting flange maintained at room temperature, gas pressure shall be set at values of 150, 225, 375 and 500 psig. Error in the output of the test gage shall be determined under these conditions.

2.3 Condition 3: With gas temperature set at approximately 540°C (1004°F), and pressure stabilized at 70 psig, the flange temperature shall be increased to approximately 100°C (212°F) and 200°C (392°F). Error in the output of the test gage shall be evaluated under these conditions.

2.4 Condition 4: With gas pressure stabilized at 40 psig and the temperature at 800°C±30°C (1472°F) the breadboard test gage shall be subjected to 100 cycles between room temperature and 800°C. At the conclusion of this test, the gage shall be recalibrated. A permanent record of the cycling test shall be obtained on a recording oscillograph chart.

2.5 Condition 5: (Interchangeability) A second breadboard unit shall be tested at 70 psig and at temperatures of 20°, 400°C, and 540°C with flange at room temperature. Results shall be compared with the first gage tested. The third breadboard unit shall be tested at gas pressure 70 psig and temperatures of 20°C, 400°C, and 540°C with flange at room temperature. Results shall be compared with gages number 1 and number 2.

3. EVALUATION OF TEMPERATURE TIME CONSTANTS:

3.1 Condition 1 (High Weight Flows): With gas temperature set at approximately 540°C (1004°F) and with the flange at room temperature, time constants shall be determined at pressure levels of 20, 50, 100, and 200 psig for one of the breadboard gages in the HTHP test apparatus. The by-pass line shall be utilized to subject the gage to a quasi-step change to room temperature and the time constant shall be evaluated from the recorded transient on an oscillograph chart.

3.2 Condition 2 (Low Weight Flows):

3.2.1 Test Facility: An atmospheric inlet wind tunnel facility is utilized for this test. The wind tunnel test section shall be sufficiently large to provide uniform (±1%) flow velocity over the outer one inch of the gage length as well as three quarters of an inch beyond the end of the gage. The gage shall be mounted in a test fixture similar to that shown in Figure 1. Heated air shall be ducted into the gage inlet at a particular wind tunnel flow setting and when the temperature is stabilized, the trigger shall be pulled giving a step temperature change between the heated air temperature and the total temperature of the wind tunnel flow.

3.2.2 Test Procedure: The same breadboard gage as tested under Condition 1 shall be installed in the test fixture and immersed in the wind tunnel test section. Time constants shall be obtained at three settings corresponding to weight flows below the value of 16 pounds per second in an eight-inch pipe. The Mach numbers shall be set at approximately 0.1, 0.2, and 0.3 for a condition of one atmosphere total pressure. Time constants shall be evaluated from the recorded transient on an oscillograph chart.

3.3 Condition 3 (Interchangeability): The remaining two breadboard gages shall be tested either according to Condition 1 at 20 psig or according to Condition 2 at 0.2 Mach number and the time constants shall be compared to that of the first unit.

3.4 In evaluation of time constants at Conditions 1, 2, and 3, corrections shall be made for the facility time constant, or the deviation between the actual temperature change and a true step-change.

4. VIBRATION TEST: One of the breadboard gages shall be vibrated along the two coordinate axes normal to the gage axis. The gage shall be subjected to fifteen minutes of cycling between 700 and 2000 cycles per second sine wave input at 35 G's peak with 20-2000 cycles per second random excitation at 1.0 G^2/cps superimposed for each of the above two axes. The gage output leads shall be monitored for continuity and insulation breakdown at approximately 3 VDC applied voltage during the entire 30 minutes of vibration testing.

5. HIGH PRESSURE, HIGH TEMPERATURE GAS LEAKAGE TEST:

5.1 Test Facility: The test facility is shown diagramatically in Figure 2. The chamber and receiver are made of inconel as is the pressure line. An Aeroquip 5139-4H-150 Conoseal V-clamp is used to join the chamber to the receiver insuring a positive gas seal. A gas tight seal between the MS-33656-4 gage mounting and the AND-10050-4 recess is provided through the use of a Harrison 12100-NA-4 K-seal. The arrangement insures that all of the gas which leaks through the Model 117B temperature gage enters the graduated cylinder and displaces the water therein.

5.2 Procedure: The chamber shall be heated to 800°C as indicated by the potentiometer (Figure 1). Helium gas at 800 to 900 psig shall be applied to the chamber interior and timing of the collection of gas in the graduated cylinder using a stop watch shall be started concurrently. After thirty minutes, the amount of helium gas collected shall be measured at the water line inside the graduated cylinder. A collection of 50 cubic centimeters or more of gas in thirty minutes constitutes a failure of the leakage test. All three breadboard gages shall be subjected to this test.

6. THERMOELECTRIC OUTPUT CALIBRATIONS:

All three gages shall be checked for thermoelectric output in an agitated oil bath at approximately 100°C and 500°C using standards and methods according to NBS Circular No. 590. Calibrations shall be made before and after the aforementioned series of performance and environmental tests. Variations of 1% or greater between the first and second calibrations shall consititute a failure of performance.

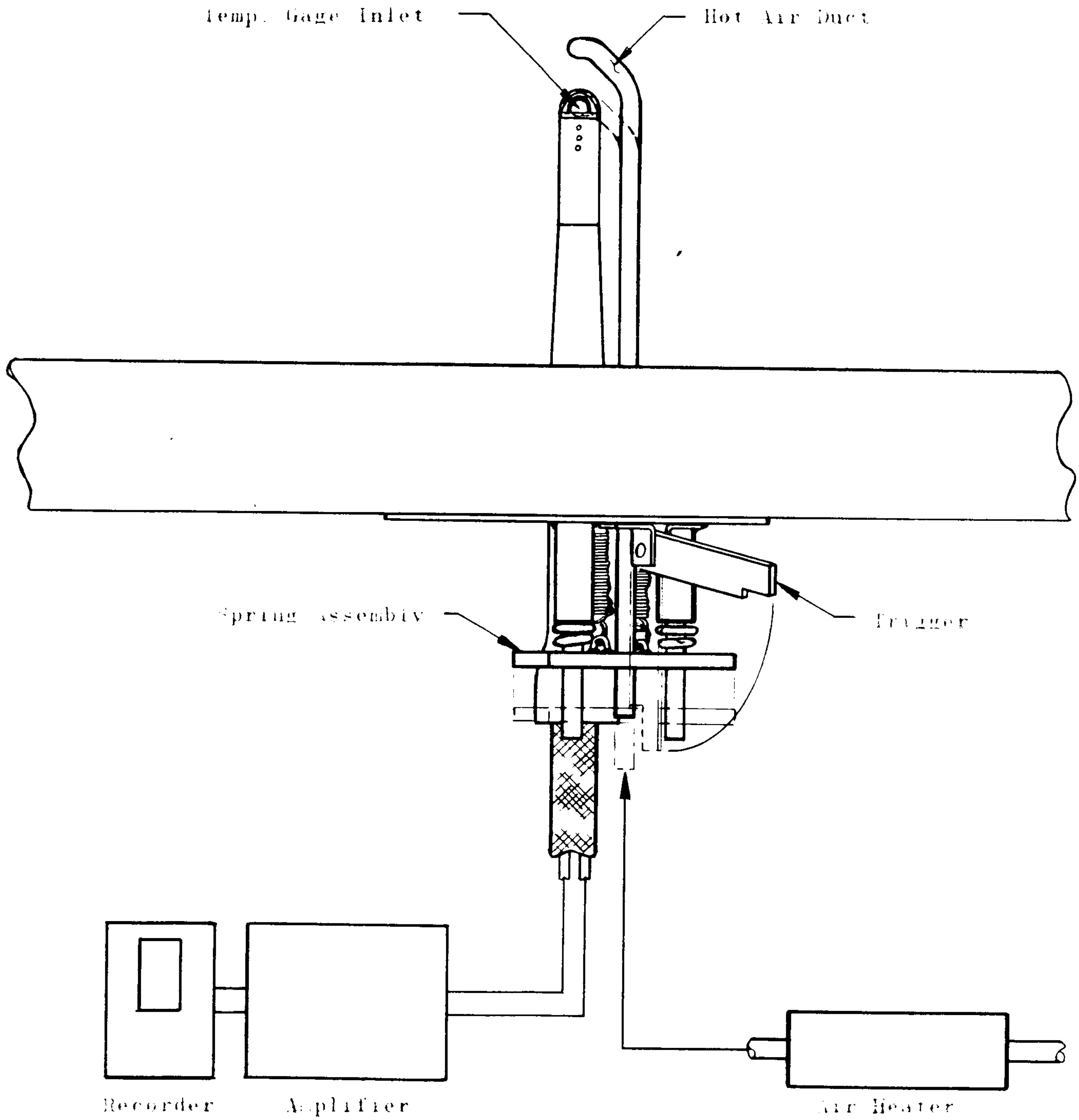
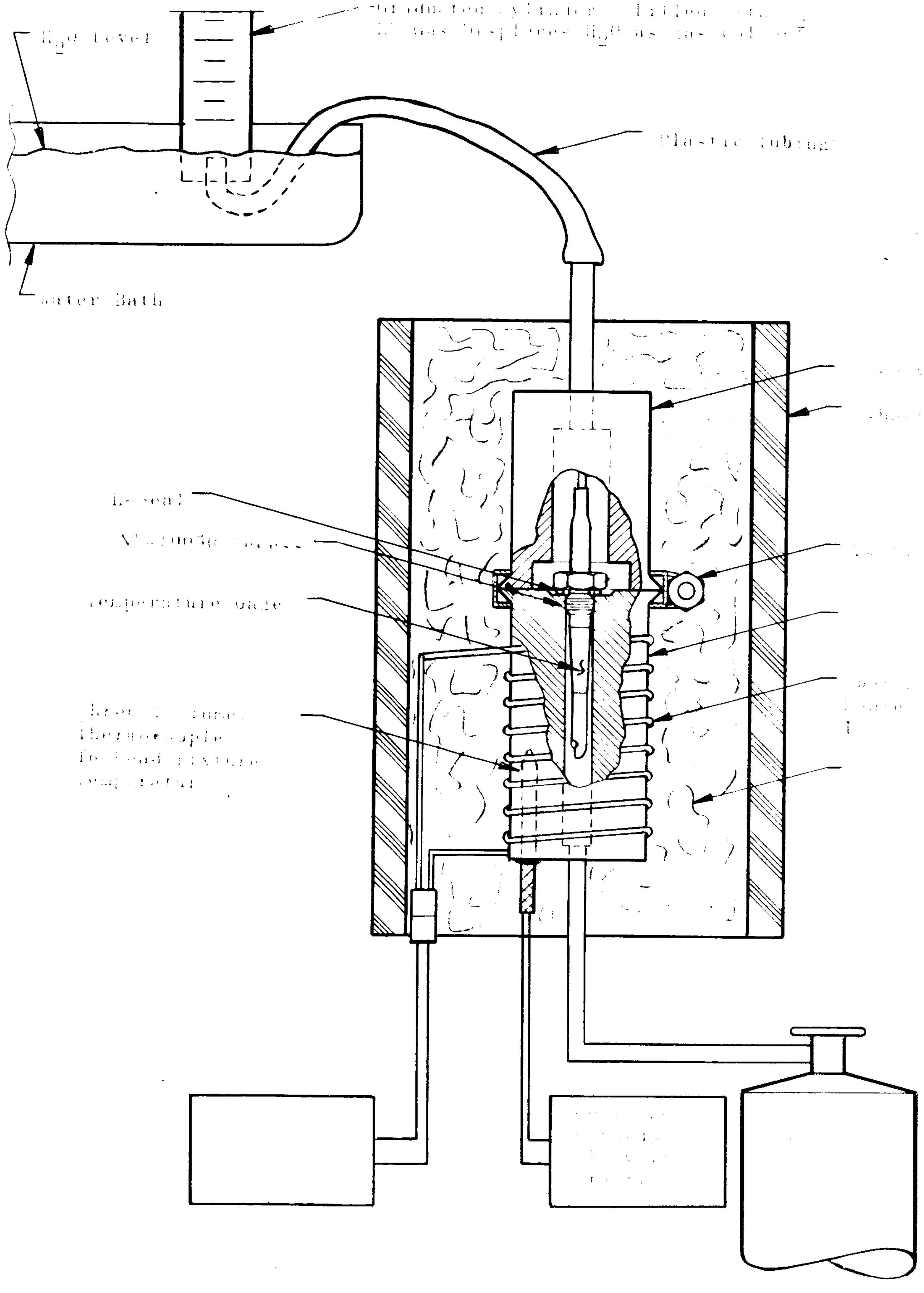


FIG. [illegible] Constant Fixture


H_2O level
Plastic tubing